MARINE PILING INVESTIGATIONS

NATIONAL RESEARCH COUNCIL

A fine of one cent per day per volume shall be charged for over-time, and must be paid before the delinquent can take any more books.

Hand books, indexes, current numbers or unbound files of periodicals, books belonging to the Clemens Herschel Special Library, and new books not yet placed on the regular shelves must not be taken from the rooms.

Books of unusual value are marked with a star (*), and must not be taken from the rooms, except by written permission from the Librarian, to be filed by the attendant.

Any person mutilating or losing a book shall pay for the damage, or replace the book.

Any one who violates the above rules may, upon written request from the Librarian to the Board of Government, be debarred from the privileges of the library for such time, not less than three months, as the Board of Government may determine.

(Revised June 16, 1915.)

MARINE STRUCTURES

THEIR DETERIORATION AND PRESERVATION

MARINE STRUCTURES

THEIR DETERIORATION AND PRESERVATION

REPORT

of the

COMMITTEE ON MARINE PILING INVESTIGATIONS
of the DIVISION OF ENGINEERING AND INDUSTRIAL
RESEARCH *of the* NATIONAL RESEARCH COUNCIL

By

WILLIAM G. ATWOOD and A. A. JOHNSON

with the collaboration of William F. Clapp, of Robert C. Miller, of the University of California, and of H. W. Walker, H. S. McQuaid and Marjorie S. Allen, of the Chemical Warfare Service, U. S. A.

Published by the
NATIONAL RESEARCH COUNCIL
Washington, D. C.

Printed in U. S. A.

FEDERAL PRINTING CO., NEW YORK

Prefatory Note

THIS report presents the results of work done by the Committee on Marine Piling Investigations of the Division of Engineering and Industrial Research of the National Research Council. In its work the Committee was assisted by the Divisions of Biology and Agriculture and of Chemistry and Chemical Technology of the Council. The Committee wishes to acknowledge also the generous contributions of funds and services by a large number of other agencies and individuals. Without these contributions it would have been impossible to have carried on the investigations which are reported in the following pages.

While these investigations were planned by the Committee, the credit for their administration is due to Colonel William G. Atwood, Director of Investigations for the Committee. Full credit is also due to Colonel Atwood and to Mr. A. A. Johnson, Assistant to the Director, for the writing of this report, with the exception of those sections for which other authors are indicated.

The Committee presents this report with the distinct realization that much remains to be done in future study on the several phases of the problem of the protection of structures in sea-water. It is believed, however, that the work of the Committee has been brought to a stage where such a compilation as this of results already obtained is warranted and it is hoped that the data here brought together may be found to be of value to the engineering profession.

R. T. BETTS,

Chairman, Committee on
Marine Piling Investigations
National Research Council

TABLE OF CONTENTS

Delaware,
rn Rail

MARINE STRUCTURES

Their Deterioration and Preservation

CHAPTER I

INTRODUCTION

Organization

The section of the San Francisco Bay area forming the northeastern portion of the bay contained many large and valuable structures practically all of which had been constructed on unprotected wooden piles during the 40 years preceding 1920. While San Francisco Bay proper had since 1849 been known to be infested by marine borers, none of them had been known in the northeastern section through which the waters of the San Joaquin and Sacramento Rivers were discharged.

In 1914 it was found that a species of shipworm previously unknown in, or at least unrecorded from, these waters had attacked the dikes at the entrance to the Mare Island Navy Yard and other structures in this part of the bay, and in 1917 signs of serious damage appeared in the dikes. Within the next four years practically every timber structure in San Pablo Bay and Carquinez Straits was destroyed, and those in Suisun Bay were attacked. Local engineers, chemists and biologists formed a committee for the purpose of endeavoring to devise protective measures. On account of the magnitude of the problem and its importance to all sections of the country, members of this committee requested the National Research Council to organize the study on a nation-wide scale.

For this purpose the National Research Council organized the Committee on Marine Piling Investigations to study the preservation of wooden structures from the attack of borers and to conduct an investigation into the value and proper use of the various substitutes for timber of which concrete is the most important.

This Committee consisted of the following members:

R. T. Betts, Chairman	Construction Engineer—Chief Engineer of the Robbins-Ripley Company, New York City
George J. Ray, Vice-Chairman	Chief Engineer of the Delaware, Lackawanna and Western Railroad, Hoboken, N. J.
Albert L. Barrows, Secretary	Biologist—Assistant Secretary National Research Council, Washington, D. C.
W. D. Bancroft	Chemist — Professor of Physical Chemistry, Cornell University, Ithaca, N. Y.

Alfred D. Flinn	Civil Engineer — Director of the Engineering Foundation, New York
George M. Hunt	Wood Preserving Specialist—U. S. Forest Service, Madison, Wis.
Charles A. Kofoid	Biologist — Professor of Zoology, University of California, Berkeley, Cal.
Col. John Stephen Sewell	Concrete Specialist—President of the Alabama Marble Company, Birmingham, Ala.
Hermann von Schrenk	Consulting Timber Engineer, New York Central R. R., N. Y., N. H. & H. R. R., etc., St. Louis, Mo.

Hon. C. H. Huston, Assistant Secretary, Department of Commerce, was designated by the President as a member of the Committee representing the Federal Government, and served as such for a short time until his resignation from the Government service.

The Committee organized early in 1922, and in February engaged Col. William G. Atwood as Director. Some time was spent in studying the problem, planning the work, securing funds and arranging for the assistance and cooperation of the various organizations interested.

In March the Director appeared before the annual meeting of the American Railway Engineering Association, which is also the Engineering Division of the American Railway Association, and explained the plans for the investigation. The American Railway Engineering Association recommended to the American Railway Association and the individual roads having waterfront properties that the investigation be supported by the contribution of services, supplies and money. The project was also presented, under the auspices of the National Research Council and the National Academy of Sciences to the various United States Government Departments and their support and assistance solicited. The plans were approved, active assistance was promised and has since been enthusiastically given by the following bureaus:

Treasury Department	United States Coast Guard
Navy Department	Bureau of Yards and Docks Bureau of Construction and Repair
War Department	Quartermaster Corps Corps of Engineers
Department of Agriculture	Forest Products Laboratory
Department of Commerce	Lighthouse Service Bureau of Fisheries United States Coast and Geodetic Survey

During the winter of 1922-23 it was found that the biological studies had progressed to a point where studies of toxicity and wood impregnation were desirable, and the Chemical Warfare Service of the Army took up this work. The necessary funds were supplied by the Bureau of Yards and Docks of the Navy, the Quartermaster Corps of the Army and the Department of

Commerce, which also made available the laboratory facilities of the Bureau of Fisheries at Beaufort, N. C.

Since it appeared probable that the harbor of New York might be subject to attack, a committee consisting of representative engineers, biologists and chemists, under the chairmanship of Mr. E. P. Goodrich, was formed to cooperate with the National Committee.

The existing San Francisco Bay Marine Piling Committee was at its own request designated as a similar cooperating body.

The central office of the Committee has been maintained in the building of the Engineering Societies, 29 West 39th Street, New York City, and the space occupied has been furnished by the Engineering Foundation. The force employed has consisted of the Director, Assistant to the Director, and usually two stenographers.

The function of this organization has been to act as a clearing house for information regarding the problem, to make a study of existing literature, to plan and direct the field and laboratory investigations, to coordinate the work of investigators along various lines, to prepare for publication information developed by study and experiment, and to furnish useful information to owners of waterfront structures. In addition the Director has acted as the executive for the New York Committee, and for the work of that committee he employed, for varying periods, an engineer, a chemist, and a biologist. The Director has made addresses or presented papers before the Municipal Engineers of New York, the American Railway Engineering Association, the American Society of Civil Engineers, the American Association of Port Authorities and the American Society for Testing Materials, and is serving as a member of the Marine Piling sub-committee of the Committee on Wood Preservation of the American Railway Engineering Association, while the Assistant to the Director is a member of the Masonry Committee of the same organization. The Director and the Assistant to the Director have also presented a joint paper before the American Society of Civil Engineers on the "Disintegration of Cement in Sea Water." In addition to papers presented to the above-mentioned societies, articles written in the Director's office or prepared from data furnished from that source have appeared in the "Railway Age," "Engineering News-Record," "South Atlantic Ports," "World Ports," "Scientific American," "Pacific Marine Review," "Military Engineer" and other technical journals, and in the daily press.

Biological Survey

It was found that while there was much general information regarding the marine borers, there was very little accurate knowledge as to species, occurrence, habits, capacity for destruction, ecology, etc., and it was realized that a proper study of protection could not be made until this information had been collected. A biological survey was plainly necessary, and the means for doing the field work were at hand through the various organizations which had promised their cooperation.

Arrangements were made for the inspection and study of the specimens collected on the Atlantic and Gulf Coast and the Caribbean Islands by Mr. W. F. Clapp of Cambridge, Mass., and with Dr. C. A. Kofoid and Dr. R. C. Miller of Berkeley, Cal., for similar work with specimens collected on the Pacific Coast and Islands. Specimens from the immediate vicinity of New

York received their preliminary inspection from Dr. S. L. Kornhauser and Mr. F. A. Varrelman, who were employed by the Director's office for the New York Committee for about one year. Mr. Clapp was first furnished with laboratory facilities by the Museum of Comparative Zoology, Harvard University, and later by the Massachusetts Institute of Technology. The University of California furnished similar facilities to Dr. Kofoid and Dr. Miller, and similar assistance for the New York work was given by the American Museum of Natural History.

Valuable advice and assistance have been received from Dr. Paul Bartsch and Dr. Waldo Schmitt of the United States National Museum (Smithsonian Institution) of Washington, from Dr. C. H. Townsend of the New York Aquarium, and Mr. Roy Miner of the American Museum of Natural History, and from Dr. E. L. Mark of Harvard University, Dr. Harriet Richardson Searle, Mr. Austin H. Clark, who served on the Committee as biologist until February 4, 1922, and was later associated with this work as consulting biologist, and others.

At the same time that the collection of specimens was going on, observations at selected points were made as to salinity and temperature, and at such additional points as laboratory facilities were available oxygen content and hydrogen ion concentration have been determined.

All this biological and chemical work has been carried on without cost to the committee except for some minor supplies, small payments to the assistants of Mr. Clapp and Dr. Kofoid, and the salaries of the New York chemist and biologists.

Substitutes for Timber

Since the supply of available timber for harbor and other construction is rapidly diminishing and the cost just as rapidly increasing, the use of other materials is becoming of great importance. The two principal materials so used are metal and concrete, either alone or in combination, and a large amount of information has been collected and published as to the service records of structures of these materials.

Concrete is far the most important of the substitutes for timber, and is also used for the protection of timber, and since it is known to deteriorate in sea water, a study of this material is fully as important as, if not more so than, an investigation of means for protecting timber against borers. A study of service records and reports showed that this deterioration was much more general and much more serious from an economic standpoint than has generally been thought to be the case.

American and foreign records indicated that the chemical failure of the cement was one of the most important causes of failure, and the paper on this subject presented before the American Society of Civil Engineers has received wide discussion and aroused much interest. Announcement has been made that manufacture of one of the foreign cements to which attention was called in this paper will be commenced in the United States in the spring of 1924, and the importation of materials for improving the quality of Portland cement has also recently been arranged for.

A series of experiments has been planned for the testing of materials found in the United States and appearing to have similar qualities to those produced abroad, as well as the development of proper methods of mixing them with Portland cement.

Finance

The cash contributions to the support of the committee have been made by the following organizations:

Baltimore and Ohio Railroad
Bangor and Aroostook Railroad
Boston and Maine Railroad
Central of Georgia Railroad
Central Railroad of New Jersey
Chesapeake and Ohio Railroad
Delaware, Lackawanna and Western Railroad
Erie Railroad
Florida East Coast Railway
Kansas City Southern Railway
Lehigh Valley Railroad
Long Island Railroad
New York Central Railroad
New York, New Haven & Hartford Railroad
Norfolk and Western Railroad
Pennsylvania Railroad
San Antonio and Aransas Pass Railroad
Santa Fe System
Seaboard Air Line Railroad
Southern Railway
Southern Pacific Railroad
Virginian Railway
American Sugar Refining Company
Atlantic Steamship Lines (Southern Pacific Company)
Cunard Line
Port of New Orleans
Barrett Company
National Research Council

In addition to their cash contributions, these organizations, the bureaus of the Federal Government, departments of State and municipal governments, industries and other property owners, have furnished services amounting in value to more than double the cash contributions.

The American Railway Engineering Association, in addition to the extremely valuable assistance of their organization in the carrying on of the entire investigation, has allowed the use of the plates showing the results of water analyses and a number of others which originally appeared in the reports of the Committee on Wood Preservation (Committee XVII) in 1923 and 1924.

CHAPTER II

BIOLOGY

The destructive marine boring animals have two distinct methods of attack, in accordance with the group to which they belong.

The molluscan borers enter the timber as minute young individuals and burrow and grow at the same time, but never enlarge the entrance hole. The result is that the interior of the timbers inhabited by them may be thoroughly honeycombed without the exterior exhibiting any evidence on the outside except the small and easily overlooked entrance holes to show that any attack has occurred. The size, shape and character of the borings vary greatly with the different genera.

The wood-boring Crustacea run shallow galleries just beneath the surface of the structure, but since these animals are found in great numbers, frequently two to three hundred per square inch, their work thoroughly destroys the outer layer of the wood which is washed away and a new surface is opened to attack. This form of attack is less dangerous than that of the boring Mollusca, because the damage can be readily seen on casual inspection, while that resulting from the activities of the Mollusca can not.

Under conditions conducive to the greatest activity, the molluscan borers may destroy a 14 inch pile in a few months, while the crustacean borers have not been known to do this in less than a year.

The literature on the subject of marine borers gave very little information regarding the distribution of the species, the relative amount of damage of which different species were capable, or the ecological conditions under which they lived. Such knowledge is necessary in order that possible attack may be predicted and prevented or actual attack reduced in intensity or altogether stopped.

There also seemed to be little information available regarding the food requirements and breeding habits of the various species, and still less regarding the effect of various toxic substances on the borers.

Information regarding the physiology of the borers was also limited to the results of incomplete investigation of one or two species.

COLLECTION OF SPECIMENS

In order to procure specimens of as many of the existing species of borers as possible, information as to their relative and actual importance, period of activity, etc., a system of test boards was devised, and in addition arrangements were made for the collection of specimens of timber from structures which had been attacked.

The first or "1922 model" test boards consisted of a plank, or metal or concrete bar on which were fastened 24 blocks of 2 in. x 4 in. x 5 in. S. 4 S. pine (Fig. 1).

These blocks were numbered and were removed from the boards at semimonthly intervals and replaced by new blocks numbered consecutively. The inspection of several entire boards at the close of the season of 1922 showed clearly a period of cessation of growth and breeding, and since it was neces-

sary to replace a number of the 1922 boards on account of their complete destruction by borers, a slight change was made in the plan of the boards in order to get both a cumulative and a monthly record of borer attack.

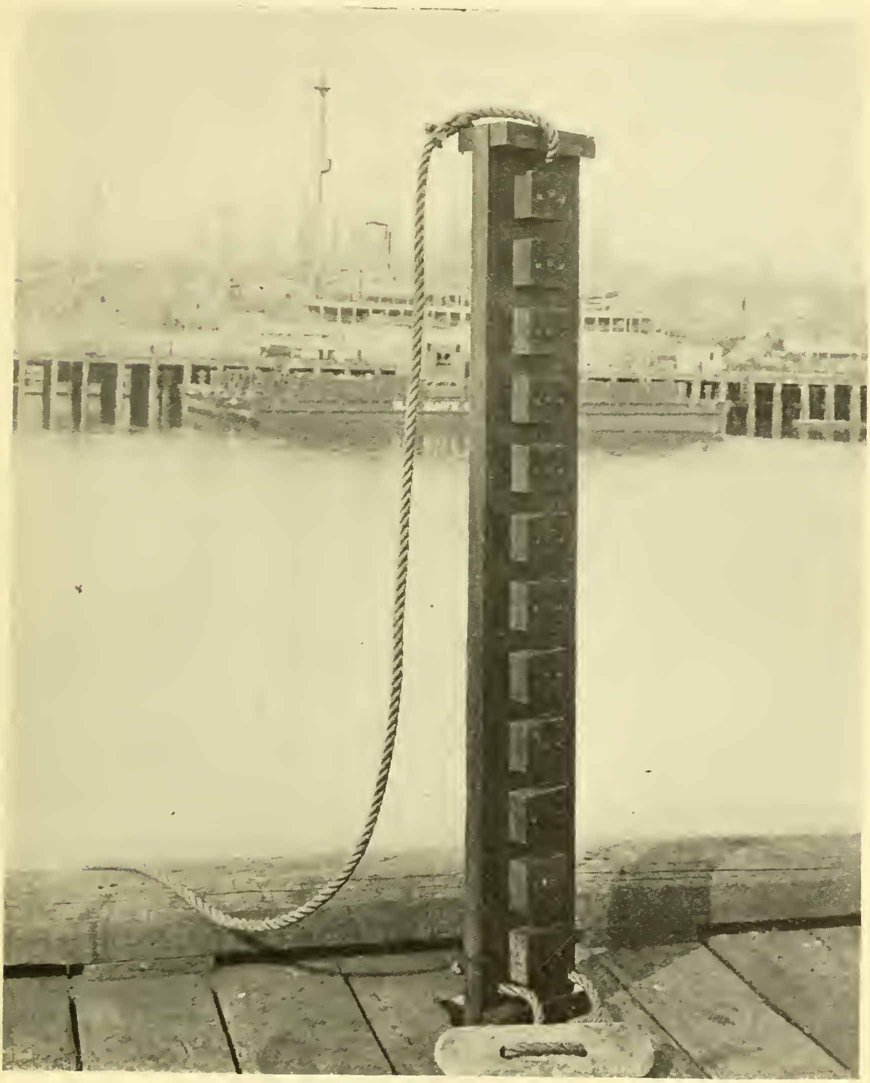


FIG. 1—STANDARD TEST BOARD, 1922 MODEL

The 1923 model board carried only 7 blocks which were 4 in. x 4 in. x 6 in. in size. Six of these blocks were numbered consecutively, and the seventh, which was placed in the center of the board, was unnumbered (Fig. 2). The lowest numbered block on the board, together with the unnumbered center block, was removed monthly, the numbered block being

replaced by another numbered block, and the center block by an unnumbered one. In this way, one block showed the cumulative attack for the period of immersion, from one to six months for the first six months, and for six months thereafter, and the other block showed the attack which had taken place during the current month. This system was very successful.

The suggestion that the occurrence of a large number of stunted forms of shipworms found in the 2 in. x 4 in. x 5 in. blocks resulting from the crowded conditions could be avoided by the use of larger blocks was the reason for the increase in the size of the blocks on the 1923 model board. The larger blocks gave little better results than the smaller ones, since the crowding persisted owing to the concentration of the shipworms in small areas on many of the blocks and the consequent production of the same stunted forms which had been found in the smaller blocks. Stunted forms will occur wherever the shipworms are badly crowded, and this crowding may occur when there is ample room for development, and where one would think that it might be avoided.

It was realized that the resources available would not permit the test board survey system to include all points on the coast where borers might be expected, but that it would be necessary to confine the investigation to the more important harbors where the possible damage would be the most serious from an economic standpoint. By a series of reports from the various governmental agencies, the railroads, municipalities and other owners of waterfront properties, a fairly accurate idea of the history of borer attacks was obtained and a general plan was formed for the distribution of the test boards. Since the placing and maintenance of the boards was a contributed service, it was not always practicable to locate boards at the most desirable points, but generally this could be done.

In all, 302 test boards were in service some or all of the time between May, 1922, and November, 1923, located in continental and insular harbors of the United States (Fig. 3) and with the assistance of the Bermuda Biological Board this Committee was able, by paying part of the expenses, to have four of these boards maintained in Bermudian harbors. A similar program of investigation has also been extended along the eastern coast of Canada by a test board system maintained entirely under the direction of the Biological Board of Canada.

The test boards of this committee were placed, maintained, and the blocks removed and sent to the laboratories, by the following agencies:

Army	73
Navy	48
Bureau of Lighthouses	12
Coast Guard	2
Railroads	89
Harbor Boards, State and Municipal Bodies	32
Industries	38
Miscellaneous Agencies	8
	302

Considering the large number of organizations with employees of all grades of responsibility and all working gratuitously, it has been very gratifying to see how carefully and regularly the blocks were removed from the boards and shipped to the laboratories. The number of failures was


MAP SHOWING
DISTRIBUTION of TEST BOARDS
COMMITTEE ON MARINE PILING INVESTIGATIONS
NATIONAL RESEARCH COUNCIL
JAN. 1924
"RR" INDICATES BOARDS MAINTAINED BY RAILROADS
"ARMY" " " " " THE ARMY
"NAVY" " " " " " NAVY
"L.H." " " " " LIGHTHOUSE SERVICE
"MUN." " " " " MUNICIPALITIES ETC.
"IND." " " " " INDUSTRIES
"MISC." " " " " OTHER ORGANIZATIONS
Alaska
5 Army
2 Navy
4 Navy
San Francisco Comm.
3 Army
2 Army
5 Navy
Hawaii
2 Navy
2 L.H.
Samoa
1 Navy
Philippine Islands
1 Navy
5 R.R.
4 L.H.
5 R.R.
5 Navy
7 R.R.
3 Army
2 Navy
1 Ind.
5 R.R.
4 Army
4 Navy
1 Mun.
1 Misc.
11 R.R.
7 Army
5 Navy
1 L.H.
14 R.R.
8 Army
7 Navy
2 L.H.
17 Mun.
7 Ind.
2 Misc.
1 R.R.
5 Army
1 Navy
3 Mun.
1 C.G.
5 R.R.
1 C.G.
2 Mun.
4 Ind.
6 R.R.
1 Army
1 Navy
1 L.H.
3 Ind.
2 R.R.
2 Army
1 R.R.
1 Army
1 Navy
1 Ind.
6 R.R.
7 Army
Bermuda
4 Misc.
Porto Rico
1 Army
3 L.H.
Virgin Islands
2 Navy
Cuba
2 Navy
Island of Haiti
5 Navy
Canal Zone
1 Navy
8 R.R.
4 Army
1 L.H.
5 R.R.
14 Army
1 Navy
7 R.R.
4 Army
1 Navy
6 Mun.
1 R.R.
2 Navy

very small. Without such intelligent and efficient cooperation this survey, with its extremely valuable results, would have been impossible.

The test blocks after removal from the boards were wrapped, while still wet, in several thicknesses of paper and mailed to the laboratories. It was found that the organisms would survive a journey of ten days or more and arrive at the laboratory in excellent condition for study.

The biological studies of the blocks and other specimens from the East

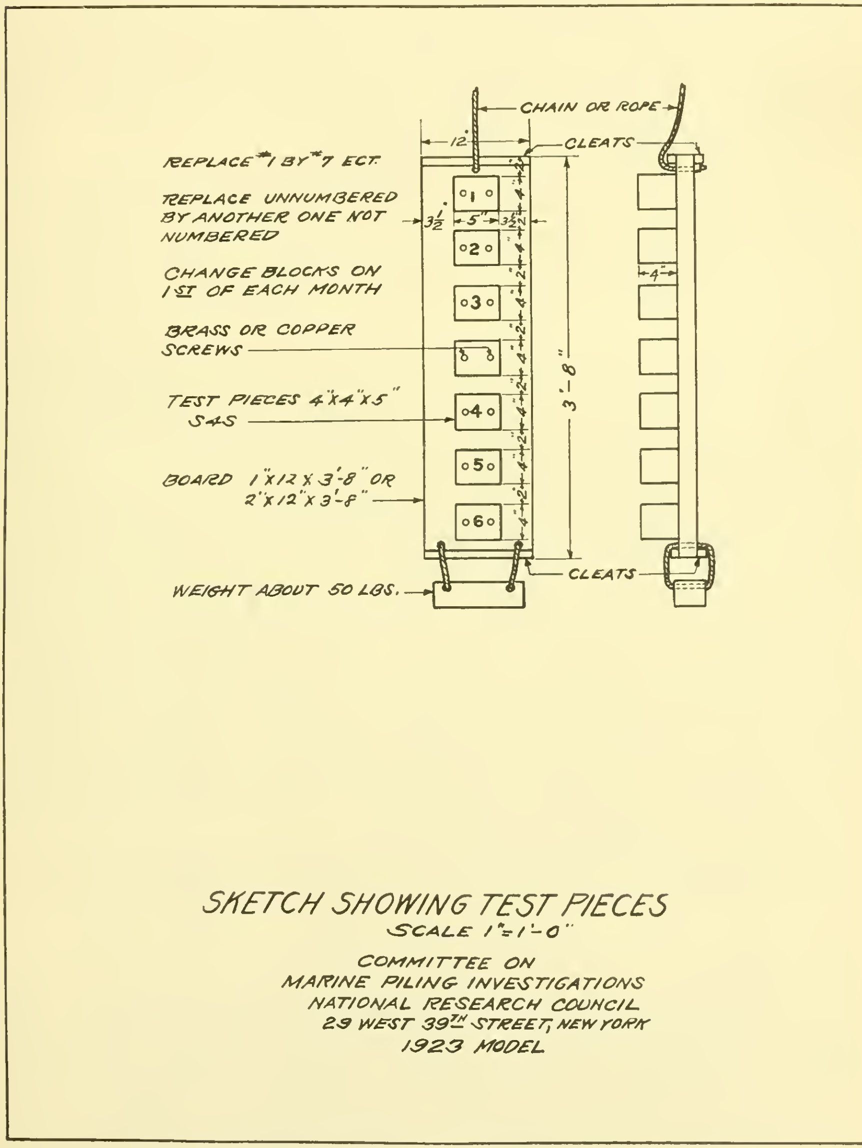


Fig. 2—Standard Test Board, 1923 Model

and Gulf Coasts and island harbors, except in the New York District, were made by Mr. W. F. Clapp. The committee has paid Mr. Clapp's expenses, but his own exceedingly valuable services have been gratuitous.

The blocks from the New York District were inspected by Dr. S. I. Kornhauser during the summer of 1922, and later by Mr. F. A. Varrelman. During their periods of employment Dr. Kornhauser and Mr. Varrelman inspected, on the ground, a large amount of timber and piling removed from structures, in addition to the test blocks.

Blocks removed from test boards on the Pacific Coast and the Pacific Islands were inspected by Dr. R. C. Miller, under the general direction of Dr. C. A. Kofoid, who was furnished laboratory facilities for his work for this committee as well as for the San Francisco Bay Marine Piling Committee by the University of California. Mr. Miller's services were contributed, but the committee paid a part of his expenses.

In addition to the regular study of specimens as above indicated, material assistance and advice have been given by the staff of the U. S. National Museum (Smithsonian Institution), and some identifications have been checked by Dr. Calman of the British Museum, and scientists of the Museum de l'Histoire Naturelle, Paris, the University of Copenhagen, and other institutions.

Regular reports of test block and timber inspections were exchanged between the biologists and the Director's office, and this information was transmitted by that office with equal regularity to those who were maintaining the test boards. As a result of the studies coordinated in this way the Director was in some cases able to warn wharf owners of attacks on their structures which had not been previously suspected.

Inspections of test boards and structures show conclusively that the test board is not an absolutely certain indicator as to the presence of borers. If the attack in a given vicinity be heavy, the test board will show it and will show that it is heavy (Fig. 4), but if there be only a few borers present, they may not appear in the board when they are present in nearby piles. Two examples of this may be cited: one, Lehigh Valley Pier A in Jersey City, N. J., where a number of specimens of *Teredo navalis* were found in piles, most piles inspected being infested, and no specimens of *Teredo* were found in the test board on the same pier; another example is found at Palatka, Fla., where piles were practically destroyed after many years service by *Sphaeroma* and none were found in the test board. In general, it may be said that *Sphaeroma* was not found in the test boards at several locations when it was known to be present.

A detailed report of the results of the study of the test boards will be found in the series of "Harbor Reports" beginning on page 221.

SPECIAL TESTS

Shingle Blocks

On account of the difficulty in obtaining undamaged specimens of the molluscan borers from the test blocks, a built-up shingle block was immersed in connection with most of the 1923 model boards. This block was about 6 inches wide, built up to a thickness of 6 inches by placing the shingles with the thick and thin ends alternating and bolting the ends securely together. As a method of collecting undamaged specimens this block was an entire success, but the animals themselves were generally

not normal, being less in diameter and longer than usual. They had no difficulty in crossing from one shingle to another, but except in a few cases seemed to prefer to stay in one shingle as long as possible. In one or two cases they seemed to work freely at right angles to the face of the shingles, and were then more nearly normal in shape (Fig. 5).

Copper Bound Blocks

The inspection of test blocks showed that the copper and brass numbers used on the blocks seemed to prevent the attachment of marine organisms in their immediate vicinity, and it therefore seemed possible that a wrapping of copper wire or strips might furnish protection to a pile. As an experiment three blocks known to be heavily infested were removed from the test board at Ft. Sumter, Charleston, S. C. One of them was wrapped with copper wire and one with ½-inch copper bands both spaced ½-inch. The three blocks were then replaced on the board and left immersed for three months longer.

When these blocks were removed after this three months' period it was found that the copper had slowed up the destruction very appreciably (Fig. 6), and that the strips were more effective than the wire. The animals in both the bound blocks appeared to be dead, while those in the unbound block were many of them alive. On account of this encouraging result, eight test boards were prepared by the U. S. District Engineer at Charleston, S. C., and immersed at Castle Pinckney, where the attack was known to be heavy. These blocks were bound with ½-in. copper strips and with wire spaced from ½ in. to 2¼ in., varying by ¼ in., with every third block unprotected as a control. Seven sets of blocks were mounted on galvanized bars and the eighth on a palmetto pole. The blocks from these boards were removed periodically as in the case of the standard boards.

One indication obtained was that palmetto was not entirely immune from attack, since both *Teredo navalis* and species of *Martesia* were found in the palmetto pole carrying the blocks on board No. 8. The specimens of *Teredo*, however, were not numerous, and were small and seemed to be incapable of causing serious damage, but those of *Martesia* seemed to work as freely as in other timber.

These eight boards were immersed at various dates between Feb. 12 and March 3, 1923. No shipworms appeared on either the control blocks or those bound with wire or bands until shortly before July 1; no barnacles* were found on the blocks having the copper spaced ½ in., ¾ in. and 1 in. before this time; and while a few specimens of *Limnoria* had appeared, no serious damage had been done. On the block with the wire or bands spaced over 1 in., barnacles were found on nearly all blocks, and the number of specimens of *Limnoria* was much greater than on those with closer spacing.

The unprotected control blocks removed about September 1 from all eight boards were very heavily attacked by *Limnoria* and were all completely filled with shipworms, *Bankia gouldi* and *Teredo navalis*. The wire bound blocks with spacing from 1 in. to 2¼ in., inclusive, were about as heavily attacked as the control blocks on which there was no copper. The blocks with wire spaced ¾ in. contained at this time about 50 specimens of *Bankia gouldi* and *Teredo navalis*, with a comparatively light *Limnoria* attack. Few of the teredine borers exceeded 100 mm. in length, which was less than half that of the animals in the control blocks.

*The barnacles found on these and other test blocks mentioned throughout this report were various species of the genus *Balanus*.

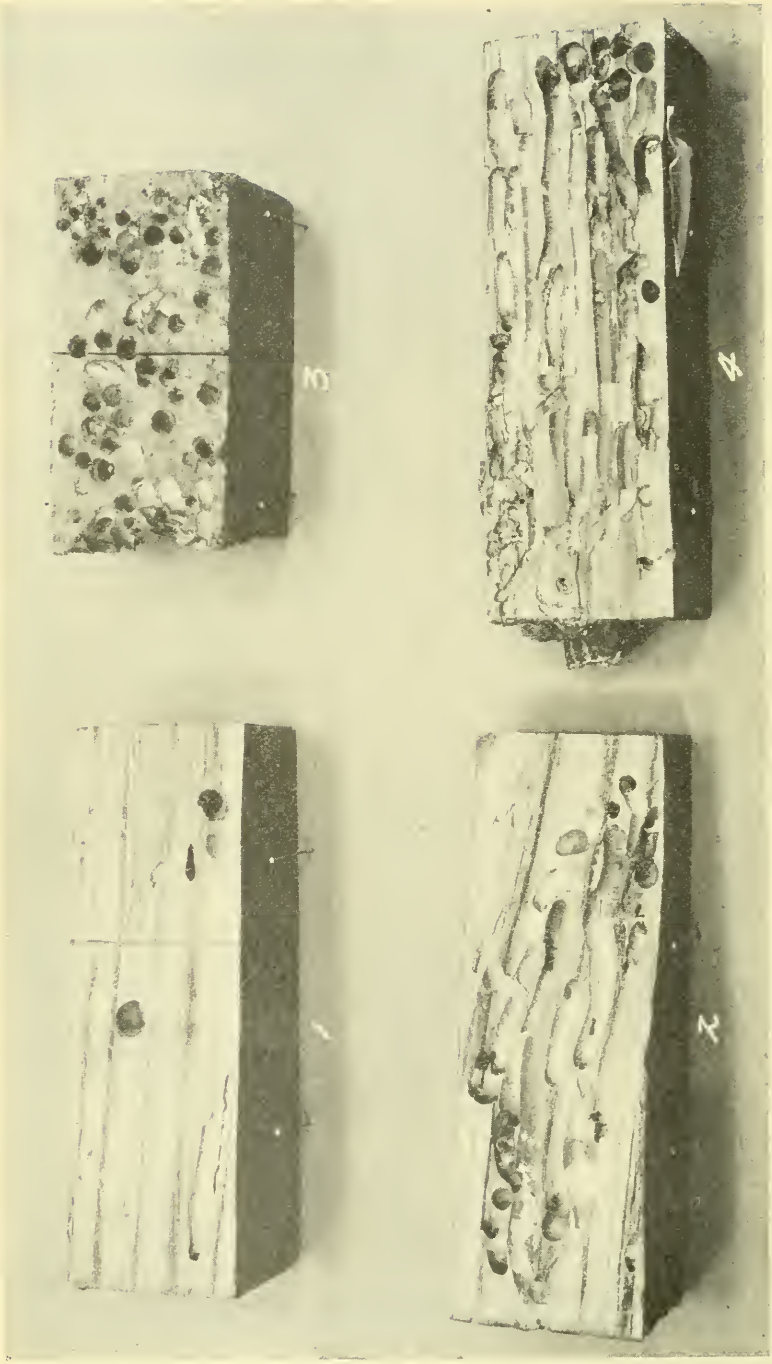


Fig. 4—Sections of Blocks from New York, New Haven & Hartford R.R. Test Boards Installed June 1, 1922.

No. 1—Slades Ferry—Block No. 8—Removed October 2, 1922.
No. 2—Slades Ferry—Block No. 9—Removed October 16, 1922.
No. 3—Slades Ferry—Block No. 10—Removed October 31, 1922.
No. 4—Warren's Cooling Pond—Block No. 10—Removed October 31, 1922.

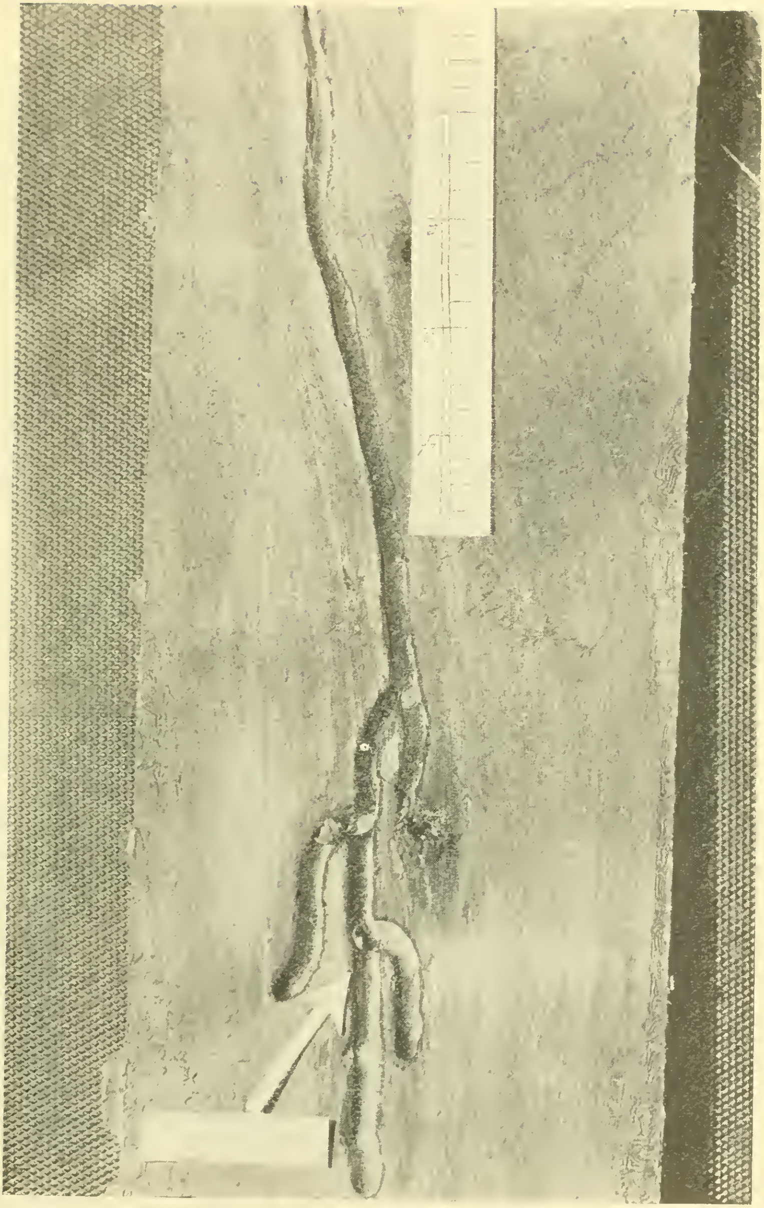


FIG. 5—BURROW OF *Teredo bartschi*; IN SHINGLE BLOCK FROM PORT EADS, LA.

The blocks with the wire on ½-in. spacing showed still less attack, for whereas *Limnoria* had destroyed the control blocks to a depth of 5 to 10 mm., the wire-bound blocks contained only about 50 animals. These bound blocks contained about 20 shipworms, a few of them 100 mm. in length, as against several hundred in the control blocks. The copper strips ½-in. wide used on half of the blocks were uniformly about twice as efficient as the wire with the same spacing.

It is clearly shown that copper has a protective influence, that strips are more effective than wire, and that the protective effect is practically lost when the spacing is greater than ¾ in. Since complete protection seems to require a spacing of less than ½ in. edge to edge for strips ½ in. in width, it is probable that the cost of application would be so great that complete copper sheathing would be more economical.

A test board on which the blocks were wrapped with copper wire and ½-in. strips arranged in the same manner was immersed at Galveston, Tex., on Nov. 11, 1922, by the Atchison, Topeka, and Santa Fe Railway. The first blocks were removed three months after immersion, but shortly afterward the board broke from its moorings and was lost. The period of inactivity of the shipworms covered a part of the period of immersion of these blocks, so that no definite conclusions can be drawn as to the efficiency of this method of protection in Galveston. The few blocks inspected tended to confirm the conclusion drawn from the Charleston tests that the ½ in. strips are considerably more efficient than the wire.

A board with blocks similarly protected with copper bands was immersed by the New York, New Haven & Hartford Railroad at Warren, R. I., on Nov. 5, 1922, and removed about one year later. The blocks with a spacing of 1½ in. and over showed no difference in attack from the unprotected blocks and had many *Balanus* on them, but those with a spacing of 1 in. or less carried no encrusting organisms. Those blocks with a spacing of ½ in. contained about 25 specimens of *Teredo navalis* with a maximum length of about 4 in. against 100 to 200 animals of about the same length in the blocks with wider spacing of the bands. The animals found in the blocks with ½ in. spacing, however, all entered from the ends of the blocks which were unprotected.

This would seem to indicate that ½ in. spacing of ½ in. wide copper bands will probably give protection in these waters.

A similar board with the blocks bound with copper-coated iron wire was immersed for the same period, but no difference in the attack could be found in the blocks with various wire spacings and the control blocks which had no wire on them.

A similar experiment with copper strips was made at Pearl Harbor. The control block was very heavily attacked by *Limnoria*, and its interior was filled with *Teredo parksi* with a probable maximum length of about 170 mm. The block was covered with Bryozoa (*schizoporella*) and *Moina* wherever *Limnoria* had left a place for them. These blocks were 2 x 4 x 8 inches, and one set of them was protected by ½-in. strips spaced 2 in. apart, and another by strips of the same width spaced 1 in. No narrower spacing was used. The board was immersed June 1, 1923, and removed Feb. 1, 1924.

There were three blocks with copper on 2-in. spacing. Encrusting organisms, including barnacles, did not show a heavy deposit. *Limnoria* had dug into the surface in portions of the block, but in none of the three blocks examined was the damage nearly as heavy as with the control block. The

number of *Teredo* burrows varied from 6 to 25, with a length slightly less than that of the animals in the control blocks. A block with $1\frac{1}{2}$-in. spacing showed very similar results. While the *Limnoria* had done considerable damage and had worked directly under the copper strips, the area attacked and the depth of penetration was not so great as in the control block. The

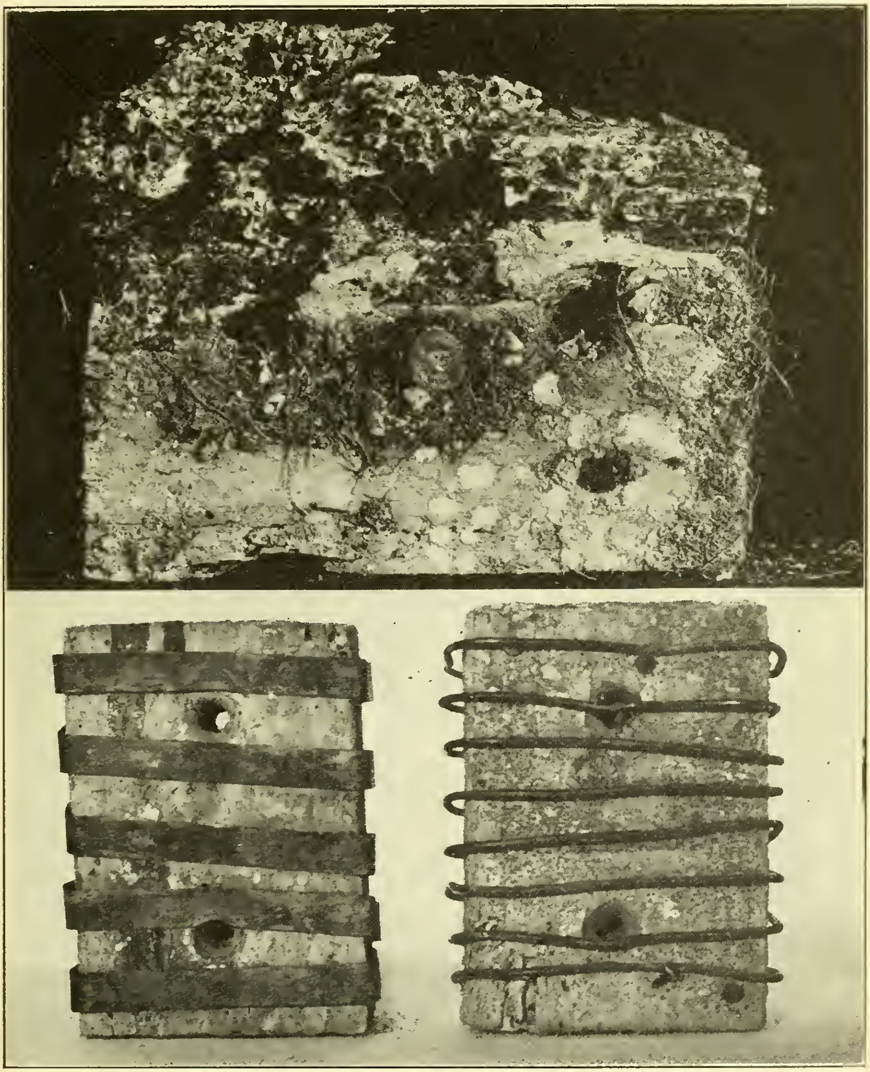


FIG. 6—TESTS OF COPPER WIRE AND BANDS, CHARLESTON, S. C.
BOARD SUBMERGED SEPTEMBER 6, 1922

Upper Fig.—Block 14 Removed February 16, 1923
Lower Figs.—Block 13 (Bands) and 15 (Wire), Metal Placed December 26, 1922; Blocks Removed February 16, 1923

block with 1-in. spacing showed about the same result with encrusting organisms, with the exception of tube worms, of which there seemed to be many more on this block than on any of the others. The *Limnoria* and *Teredo* attack was similar to that in the other protected blocks, and the extent of damage did not vary greatly from them.

It would therefore appear that the copper strips 1 in. apart, while they caused a much less intense attack, did not give ultimate protection.

European reports indicated that there was a strong probability that wrapping with flat steel would give as good protection as the system of "scupper nailing," which had been used with considerable success in Dutch and Scandinavian harbors. In order to test this, boards were prepared in the same way as those with copper strips and with the same variation in the spacing. The boards were made and immersed by the Seaboard Air Line at Charleston, S. C., and by the Navy at St. Thomas, V. I., and Coco Solo, C. Z.

The special test board at Coco Solo was immersed May 9, 1923, and removed Oct. 9, 1923. Several series of blocks were also removed at intervals during this period.

The blocks protected by bands or wire spaced over ¾ in. showed that the iron had little or no effect on either *Limnoria* or teredine borers, and with less distance between the wire or bands the blocks were heavily attacked. Some blocks with bands at ½ in. spacing which were heavily attacked contained, after three months immersion, a number of shipworms of comparatively small size and all dead with the burrows filled with iron rust.

This test indicates that at Coco Solo where there are many species of shipworms and the attack is very heavy, iron wire gives little or no protection and iron bands very little, even when spaced only ½ in. The corrosion of the metal is very rapid and the effect of the iron would probably be lost in a comparatively short time.

The Newport News Shipbuilding and Dry Dock Company at Newport News, Va., installed 13 boards, each carrying blocks cut from sap and heart timber. These boards were heavily galvanized plates set in guides at various angles with the current and at various depths in order to show variation in the attack. (Fig. 7).

There proved to be no difference in the attack on heart and sap wood.

These tests were installed about Feb. 1, 1923, and none of them showed attack before June 15. The blocks removed on that date showed some barnacles and Bryozoa, except those within the tidal range on which there was a deposit of oil. On July 2 the blocks showed an increase in the number and size of encrusting organisms, but no borers, while the blocks removed on July 16, all but two of them located close to low water, contained a few specimens of *Teredo navalis* and *Bankia gouldi*, none exceeding 30 mm. in length.

The Aug. 1 blocks all showed much heavier attack and rapid growth, many of the blocks containing animals 150 mm. long.

The later blocks showed such irregularities in the intensity of attack that no conclusions can be drawn as to the effect of depth or direction of current. There was no attack on the blocks appreciably above mean low water.

In addition to these experiments long time tests have been started in the following locations:

Fig. 7—Type of Test Board Used by the Newport News Shipbuilding & Dry Dock Co., Newport News, Va.

The Bureau of Lighthouses placed one test pile sheathed with monel metal at the Cat Island Light Station, Fla., on Feb. 21, 1923, and one sheathed with copper on Jan. 16, 1923. Two piles similarly protected were installed at the Key West, Fla., Depot Wharf on May 23, 1923. (See Harbor Report "Key West").

The "scupper nailing" method is being tested by the Seaboard Air Line with a test piece 4 in. x 4 in. x 5 ft., placed at Tampa, Fla., June 7, 1923. (See Harbor Report "Mississippi River to Key West"), and by the Bureau of Yards and Docks, Navy Department at Pearl Harbor, H. I., where both steel and copper nails were used (see Harbor Report "Pacific Islands").

The Grand Trunk Railway has several piles in its wharf at Portland, Me., protected by ½ in. wide copper strips spaced 1 in. apart (see Harbor Report "Maine Coast").

Test pieces of manbarklak and angelique furnished by the Colonial Government of Dutch Guiana have been installed as follows:

LOCATION	DATE PLACED	AGENCY PLACING
Fall River, Mass.	July 17, 1923	New York, New Haven & Hartford R.R.
Galveston, Tex.	July 11, 1923	Southern Pacific Ry.
Newport News, Va.	July 10, 1923	Newport News Shipbuilding & Dry Dock Co.
*St. Augustine, Fla.	July 31, 1923	Florida East Coast Ry.
**Key West, Fla.	Aug. 3, 1923	Florida East Coast Ry.
**Galveston, Tex.	Nov. 11, 1922	Atchison, Topeka & Santa Fe Ry.
**San Francisco, Cal.	Jan. 5, 1923	San Francisco Committee

*Angelique only.
**Manbarklak only.

In addition to manbarklak and angelique, several other tropical timbers are being tested by the Panama Canal authorities and the San Francisco Committee, and at the time of writing six additional pieces of turpentine wood are en route from Australia.

WATER ANALYSES

In order to obtain ecological information, water analyses were made at the location of as many test boards as possible. Wherever laboratory services could be obtained, determinations were made of salinity, temperature, oxygen content and hydrogen ion concentration; where laboratories were not available temperature and salinity were recorded, and in one location where no better arrangement could be made temperature only was recorded. The ideal times for these tests, high and low tide, were impracticable in many cases, and the time, as well as the frequency of observations, had to be governed by the labor and facilities available.

In the field laboratories of the Chief Engineer of the Board of Estimate and Apportionment of New York City, and in those of the Committee in New York, temperatures were read on a thermometer designed for such work, salinity was determined by titration with nitrate of silver, oxygen content by the method outlined in the Manual of the Public Health Association, and except in one case the hydrogen ion concentration, by the use of the La Motte comparator. The laboratory of the Babcock and Wilcox Company at Bayonne, N. J., used the electrical method of determining hydrogen ion concentration.

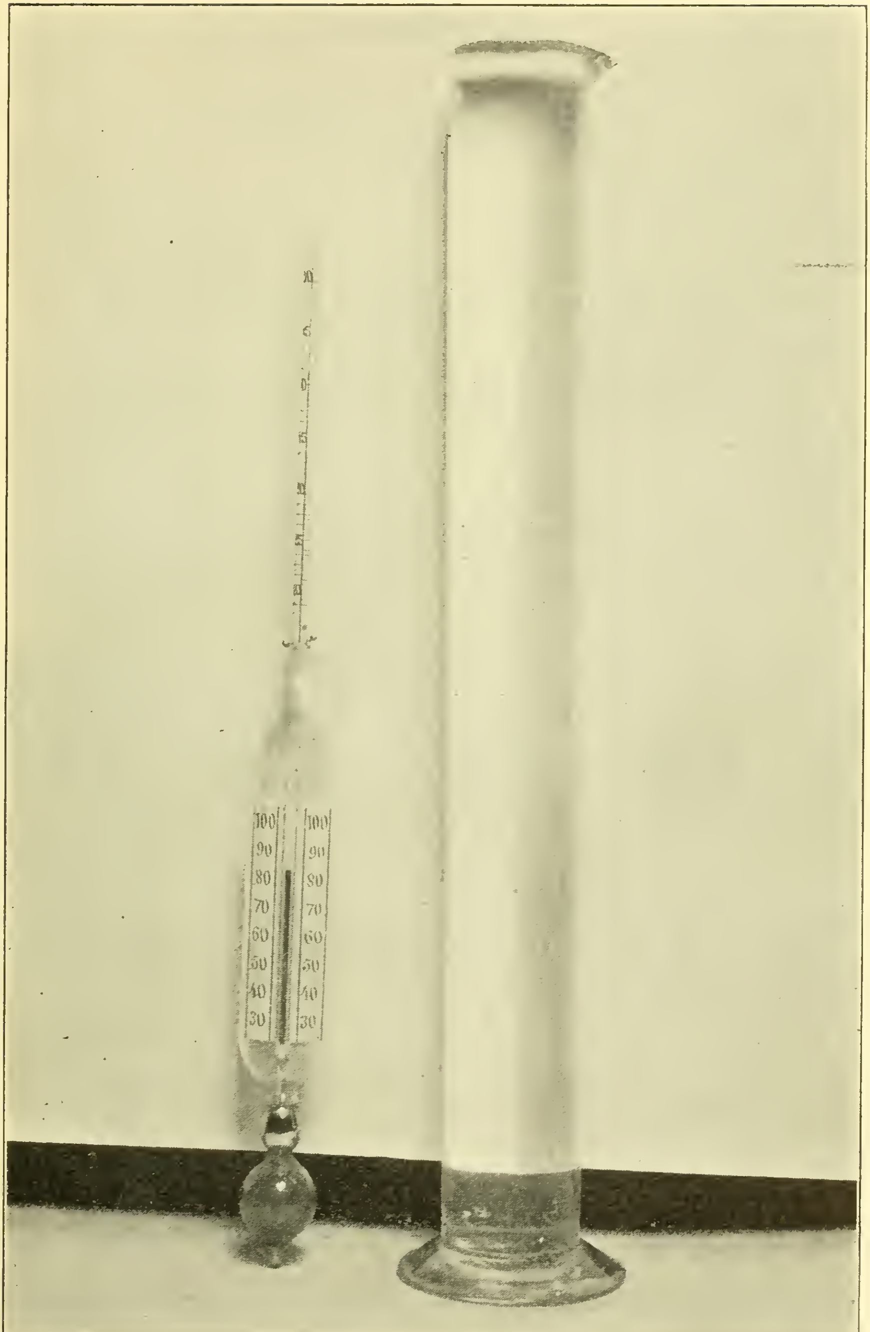


FIG. 8—SALINOMETER USED FOR DETERMINING SALINITY

At locations where laboratory facilities were not available, salinity and temperature observations were made with a "salinometer" (hydrometer) designed for the work of the Metropolitan Sewerage Commission of New York in New York Harbor prior to 1914 (Fig. 8). In some cases the Navy Department and others used hydrometers and thermometers secured from other sources. Several of the salinometers manufactured in New York were calibrated by comparison with results obtained by the titration method. Nineteen tests were made, of which two gave the same result by both methods, one showed a variation of one part of NaCl per 1000, with an average variation in the 19 tests of .05 parts of NaCl per 1000.

The results of these analyses have been plotted and will be found in the "Harbor Report Section" in the reports on the following harbors:

Boston Harbor—3 locations.	Woods Hole, Mass.—1 location.
Warren, R. I.—1 location.	Providence, R. I.—1 location.
New York Harbor—10 locations.	Norfolk, Va.—4 locations.
Baltimore Harbor—1 location.	Charleston, S. C.—1 location.
Beaufort, N. C.—1 location.	Jacksonville, Fla.—1 location.
Brunswick, Ga.—2 locations.	Pensacola, Fla.—1 location.
Key West, Fla.—1 location.	Mobile, Ala.—1 location.
Gulfport, Miss.—1 location.	Port Eads, La.—1 location.
Lake Pontchartrain, La.—1 location.	Port Aransas, Tex.—1 location.
Galveston Bay, Tex.—2 locations.	Coco Solo, C. Z.—1 location.
Corpus Christi, Tex.—1 location.	Port au Prince, Haiti—1 location.
Guantanamo, Cuba—2 locations.	Puget Sound, Wn.—4 locations.

San Francisco Bay—8 locations (Reports—S. F. Com.)

In addition to the graphs a tabulated statement of salinities and temperatures furnished by the Coast and Geodetic Survey will be found in the report on Ketchikan, Alaska, and a graph of such results furnished by the Biological laboratory of the Department of Marine and Fisheries of the Dominion of Canada will be found with the brief report on conditions in those waters. A few analyses made by the laboratory of the Department of Health will be found in the report on the harbor of San Juan, P. R.

Except for the analyses made by the chemist employed by the Committee in New York all this work was done without cost to the Committee by the various organizations indicated on the graphs. This work has added greatly to the valuable data collected in the course of the investigation, and the gratitude of all those interested should be extended to all the organizations contributing this work.

CHAPTER III

ANIMALS BORING IN TIMBER

CRUSTACEA

Three genera of this class are represented among the wood boring animals of economic importance, *Limnoria, Chelura* and *Sphaeroma.* The method of attack and the general effect on the timber is similar.

Limnoria lignorum Rathke (Fig. 9), frequently known as the "Gribble," has been known as a wood destroyer for over 100 years. It was originally identified in Norway in 1799 and caused Robert Stevenson considerable trouble in the construction of the Bell Rock Lighthouse in 1814.

Limnoria lignorum resembles an ordinary woodlouse in appearance and belongs, like the woodlouse, to the order of Crustacea known as Isopoda. The body of this animal is from ⅛ to ¼ in. in length with a width about one-third its length. It is slipper shaped and has a small head and segmented body ending in a broad tail plate which can be tilted up to close the burrow against intruders.

The head bears a pair of eyes, two pairs of short feelers or antennae, and on the under side four pairs of mouth parts, including a pair of strong horny tipped mandibles with which most of the boring is done.

There are seven pairs of legs with sharp hooked claws which enable the animal to cling to the wood and to move in its burrow or on the surface of the wood. The gills, which are in constant movement causing a steady renewal of the water for respiration, are flat membranous plates. When the animal is in the water, these plates furnish the motive power for swimming. The animal can contract its body so as to curl itself up into the form of a ball.

The sexes are separate and fertilization is internal. The eggs, which have a diameter of about one-fourth that of the body of the female, are carried in a brood pouch between the legs on the underside of the female. The number of eggs in a single brood is seldom less than six, or more than seventeen. The young when hatched differ only in size from the adults and are ready to bore at once, and they begin their work near the parent, so that an infestation generally spreads slowly from a center. A single square inch of timber may contain 300 to 400 animals of all ages.

Precise data as to the breeding season or temperature requirements for breeding are generally lacking. *Limnoria* is found apparently working at all seasons of the year, and on account of its wide distribution in water with great ranges of temperature it is probable that it has a very considerable power of adaptation. Dr. R. E. Coker found in his studies at Beaufort, N. C., that the water temperature did not fall below 16°C. until Nov. 20, 1922, but that there had been occasional readings as low as 14°C. before that time (see temperature chart Beaufort, N. C., Report page 305). No eggs were found after Oct. 26, at which time the temperature first reached 14°C. By April 14, 1923, when the mean temperature had risen to 16°C. and the minimum above 14° C., a substantial proportion of the large specimens of *Limnoria* were gravid.

Dr. Coker's studies also indicated that the period of incubation was abou: two weeks at Beaufort in the spring of 1923, and that the period when no breeding occurred was about four months from about the middle of December to the middle of April.

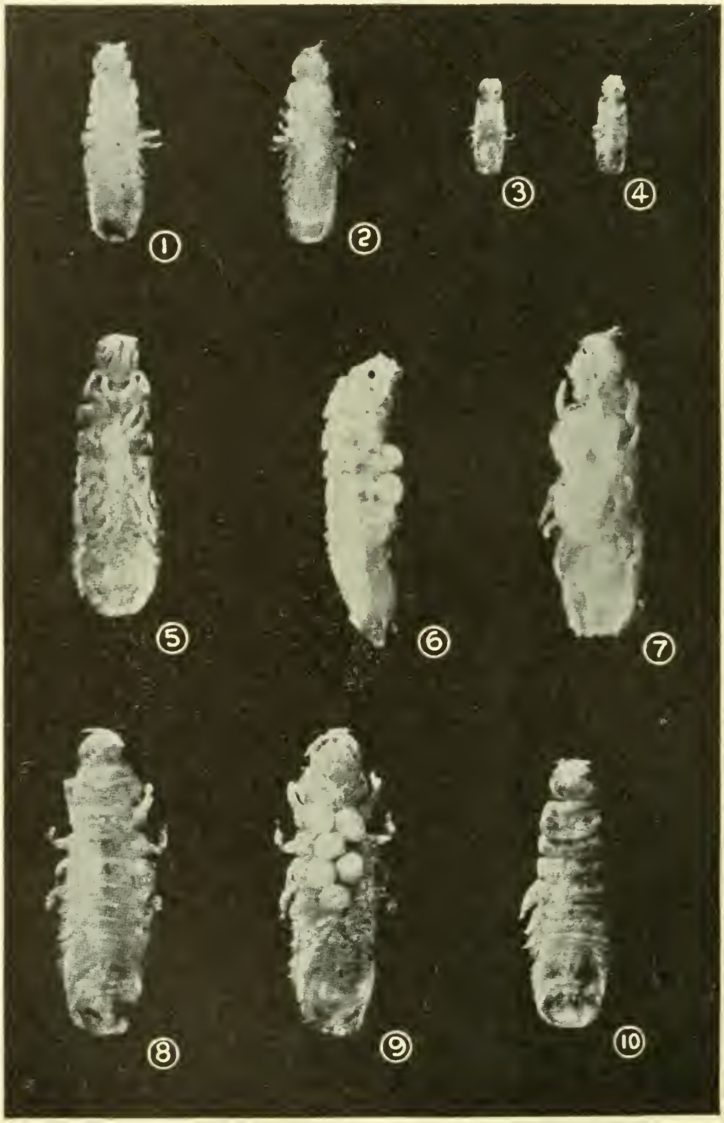


FIG. 9—*Limnoria lignorum* (RATHKE)
1-4—Young stages. 6, 7 and 9—Females with eggs. Magnified 11 diameters

The fact that *Limnoria* is very active at the North Cape in Europe and in Alaskan waters, where the temperature seldom rises as high as 14° C., indicates that the influence of a specific temperature varies with the locality.

Limnoria destroys timber by gnawing interlacing branching burrows into the surface of the wood. The burrows are generally not more than 1/20 in. in diameter and are of the same size throughout their depth. They generally follow the softer spring wood between the harder layers of autumn growth, but their burrows are so numerous that the surface layers of timbers are rapidly destroyed.

Limnoria is particularly dangerous in its attack on creosoted timber. It frequently gains entrance at a knot, abrasion, or other point of thin treatment and works in until it reaches the untreated center of the stick. This portion of the timber is promptly destroyed and the outer treated shell left intact.

Limnoria is sometimes found above normal high tide, but generally the greatest intensity of attack is between a level just below low tide and about half tide. The attack may be heavy from this level to the mud line, and some cases are recorded where piles were entirely cut off at the mud line and showed little evidence of attack within the tidal range.

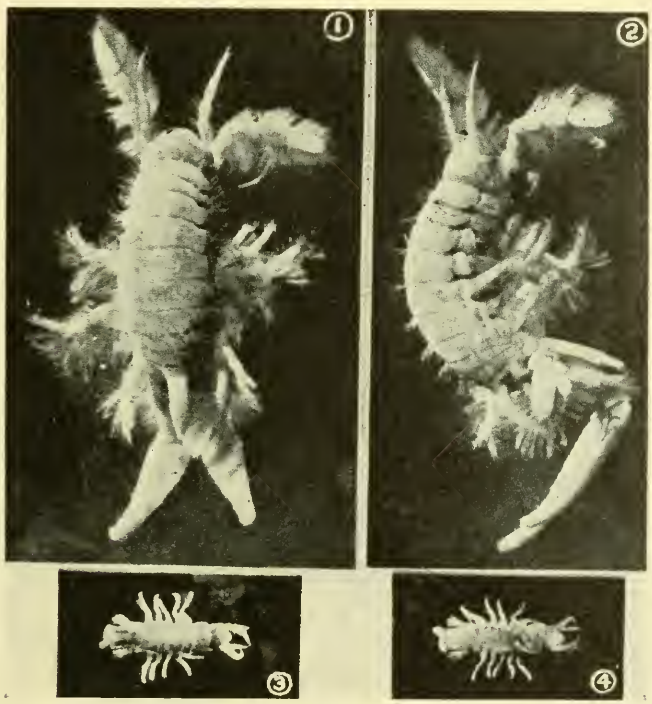


Fig. 10

1. *Chelura terebrans*, male, from Charleston, S. C., dorsal view. × 11.
2. Lateral view of same. × 11.

3 and 4. Dorsal and ventral views of female *Chelura*. × 5.

Limnoria lignorum is probably of wider distribution than any other single species of wood borer. It is reported in the east Atlantic from the North Cape to Cape Town, and on the American coasts it extends from the Gulf of St. Lawrence to the Falkland Islands and from Alaska southward.

Limnoria has been found on the test boards and specimens examined by the biologists of the Committee at the following points:

Lubec, Maine.
Cutler, Maine.
Crabtree Ledge, Maine.
Portland, Maine.
York Harbor, Maine.
Portsmouth, N. H.
Salem, Mass.
Lynn, Mass.
Boston, Mass.
Provincetown, Mass.
New Bedford, Mass.
Newport, R. I.
Dutch Harbor Island, R. I.
Warren, R. I.
Mystic, Conn.
New London, Conn.
New Haven, Conn.
Greenpoint, N. Y.
New York Harbor, East River.
New York Harbor, Lower Hudson River
New York Bay
Jamaica Bay, N. Y.
Fire Island, N. Y.
Beach Haven, N. J.
Barnegat City, N. J.
Point Pleasant, N. J.
Atlantic City, N. J.
Norfolk, Va.
Beaufort, N. C.
Charleston, S. C.
Brunswick, Ga.
Fernandina, Fla.
Channel Five, Fla.
Key West, Fla.
St. George, Bermuda.
Ireland Island, Bermuda.
Bars Bay, Bermuda.
Agars Island, Bermuda.
Tampa Bay, Fla.
Cedar Key, Fla.
St. Andrews, Fla.
Pensacola, Fla.
Gulfport, Miss.
Galveston Bay, Tex.
Aransas Pass, Tex.
Corpus Christi, Tex.
Pt. Isabel, Tex.
Fajardo, Porto Rico.
San Juan, Porto Rico.
Guantanamo, Cuba.
Port au Prince, Haiti.
Puerto Plata, Santo Domingo.
St. Thomas, V. I.
Christiansted, V. I.
Coco Solo, Canal Zone.
Mazatlan, Mexico.
Topolobampo, Mexico.
Guaymas, Mexico.
San Diego, Cal.
Long Beach, Cal.
Los Angeles, Cal.
San Francisco, Cal.
Puget Sound, Wash.
Ketchikan, Alaska.
Petersburg, Alaska.
Juneau, Alaska.
Sitka, Alaska.
Seward, Alaska.
Kodiak, Alaska.
Dutch Harbor, Alaska.
Honolulu, T. H.
Pearl Harbor, T. H.
Nawiliwili, T. H.

Limnoria andrewsi (Plates I, II) Calman was described from Christmas Island, in the South Pacific, in 1910. It is in general a smaller and somewhat less destructive species than *Limnoria lignorum*, from which it can be distinguished only by the specialist. *Limnoria andrewsi* takes the place of *Limnoria lignorum* in the blocks from Samoa, and occurs with the latter species in the blocks from Honolulu Harbor.

The limits of salinity and pollution within which the *Limnoria* can live have not been definitely determined. They, of course, live in water of normal salinity, and in many harbors have been found in highly polluted water. They have not been found in test blocks or specimens at any point at which salinity records are available where the salinity fell below fifteen parts per thousand for periods of considerable length, though in one location in Norfolk harbor it reached as low as five parts per thousand once for a few days.

A fairly heavy attack of *Limnoria* occurred at the Standard Oil piers at

Bayonne, N. J., where the dissolved oxygen content varied from 15 per cent to 70 per cent, with a general average of between 30 per cent and 40 per cent, and a hydrogen ion concentration varying from 7.00 to 8.8, with a general average of about 7.4 (New York Harbor Report, Fig. 69).

Chelura terebrans Philippi (Fig. 10), described in 1839, is a member of the order Amphipoda, which includes among other forms the ordinary "sand hoppers." It is slightly larger than *Limnoria*, and the body at the segmental joints, and also the antennae and the legs, are heavily feathered with long hairs.

It can also be readily distinguished from *Limnoria* by its larger and stronger antennae, by the pair of large tail appendages (uropods) at the posterior end of the body, and by the long spine projecting from the middle of the back.

Chelura works with *Limnoria* and in much the same manner, though the galleries which it bores are slightly larger.

Chelura is reported as a wood destroyer on the European coasts from Norway to the Black Sea, and on the Atlantic coast of North America, but it has been found in the test blocks and specimens collected by this Committee from Atlantic and Pacific harbors only at Ireland Island, Bermuda. It does not therefore appear to be of much economic importance in American waters.

Chelura insulae (Plates I, II) Calman, like *Limnoria andrewsi,* was described from Christmas Island in 1910. It can be distinguished from *Chelura terebrans* by the possession of longer antennae and much larger anterior claws or gnathopods, and reduction of the long spine mentioned above as characteristic of *Chelura terebrans* to a mere tubercle. *Chelura insulae* occurs in great numbers in the blocks from Tutuila, and occasionally in those from Honolulu Harbor. The damage is secondary to that occasioned by *Limnoria.*

Sphaeroma quadridentum Say
Sphaeroma destructor Richardson
Sphaeroma pentadon Richardson (Fig. 11.)

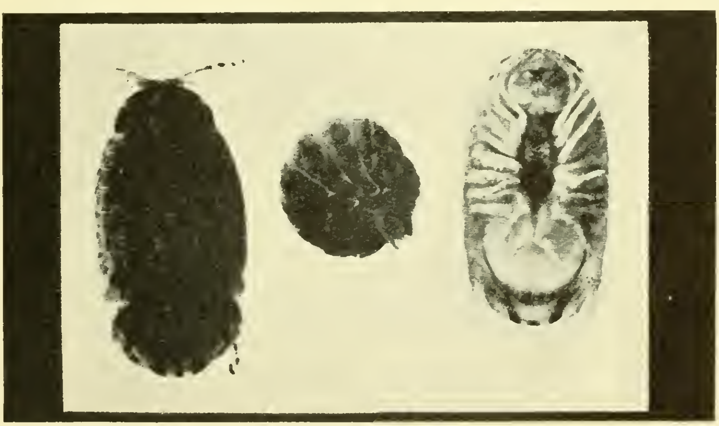


Fig. 11—Dorsal, Lateral, and Ventral Views of *Sphaeroma pentadon* Richardson

One specimen of the first named species was found in a test block from Beaufort; specimens of *Sphaeroma destructor* came from certain East Coast harbors, and of *Sphaeroma pentadon* from the West Coast.

The genus *Sphaeroma* is allied to *Limnoria* which it closely resembles in structure. The color of the species mentioned is dark olive to slightly reddish brown, frequently with lighter colored yellowish blotches on the back. They are considerably larger than *Limnoria lignorum,* sometimes reaching a size of ½ in. in length and ¼ in. in width. While their burrows are much larger than those of *Limnoria lignorum,* the animals themselves are not so numerous or so destructive.

Little or nothing is known of the development or breeding habits of the species of this genus, beyond the fact that the eggs are carried on the abdomen of the female as in the case of *Limnoria.* Since some species of *Sphaeroma* are not thought to bore wood, but only mud and soft rock, it is not probable that wood forms any important part in the food of the animal.

The species of *Sphaeroma* work generally between high and low tide, but may sometimes be found doing considerable damage at the mud line. Piles in a structure at Palatka, Fla., have been entirely cut off at the mud line by these animals (Fig. 12). This structure is over 70 miles from the ocean, and the water is supposed to be absolutely fresh, and several specimens of the same species (*Sphaeroma destructor*) have been found in test blocks at Provincetown, Mass., in water of full salinity.

The heaviest *Sphaeroma* attacks are reported from the St. Johns River, Fla., and Lake Pontchartrain, La., where the water is fresh or nearly so (see Salinity Chart Lake Pontchartrain Fig. 118), but these animals have also been found in the course of the work of this Committee at the following locations:

Sphaeroma quadridentum

Beaufort, N. C.

Sphaeroma destructor

Provincetown, Mass.	Jacksonville, Fla.
Palatka, Fla.	Tampa Bay, Fla.
Pass Manchac, La.	Lake Pontchartrain, La.
Port Eads, La.	

Sphaeroma pentadon

San Francisco Bay, Cal.

This last species is reported to exist along the Pacific Coast as far as Alaska but has been found in none of the test boards or specimens of timber outside of San Francisco Bay. These animals do not seem to attack the test boards as freely as other species of borers, even when they are present in timber in considerable numbers. They exercise a preference for very soft wood, or that already bored by *Teredo,* and hence do not constitute a serious economic problem.

A closely related crustacean, *Exosphaeroma oregonensis,* is reported to be a timber borer by the Marine Biological Laboratory of the Bureau of Fisheries of Canada at Departure Bay, Vancouver Island.

MOLLUSCA.

The most important genera of this family within the territory belonging to the United States are the *Teredo, Bankia* and *Martesia,* all three bivalves distantly related to the clam.

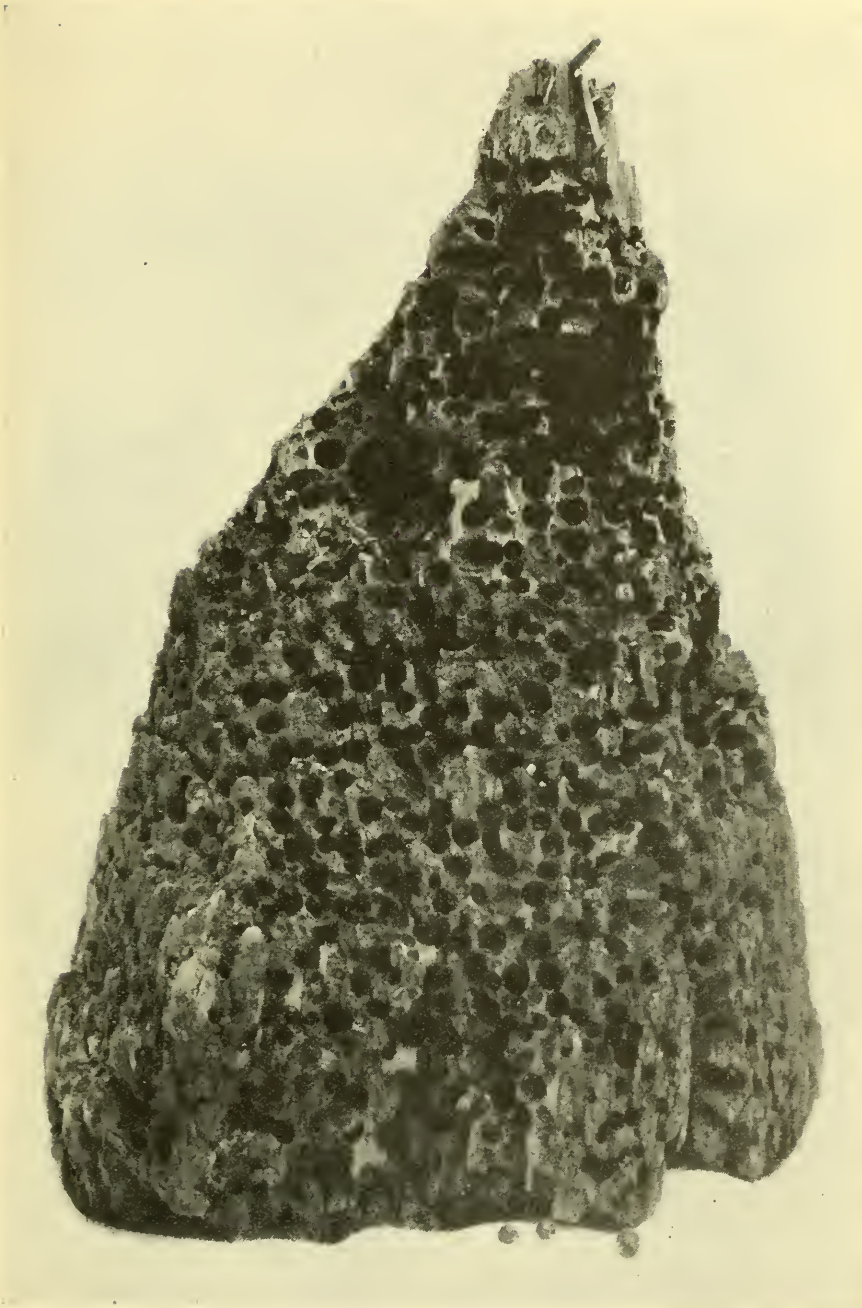


FIG. 12—SECTION OF PILE FROM FLORIDA EAST COAST RY. BRIDGE, ST. JOHNS RIVER, PALATKA, FLA. *Sphaeroma* ATTACK—17 YEARS' SERVICE.

The method of attack and general appearance of the first two genera are similar (Fig. 13). The two valves of the shell function as a highly specialized boring mechanism; the long slimy worm-like body fills the burrow, which is lined with a calcareous coating, and both *Teredo* and *Bankia* are supplied with very long siphons and with so-called "pallets."

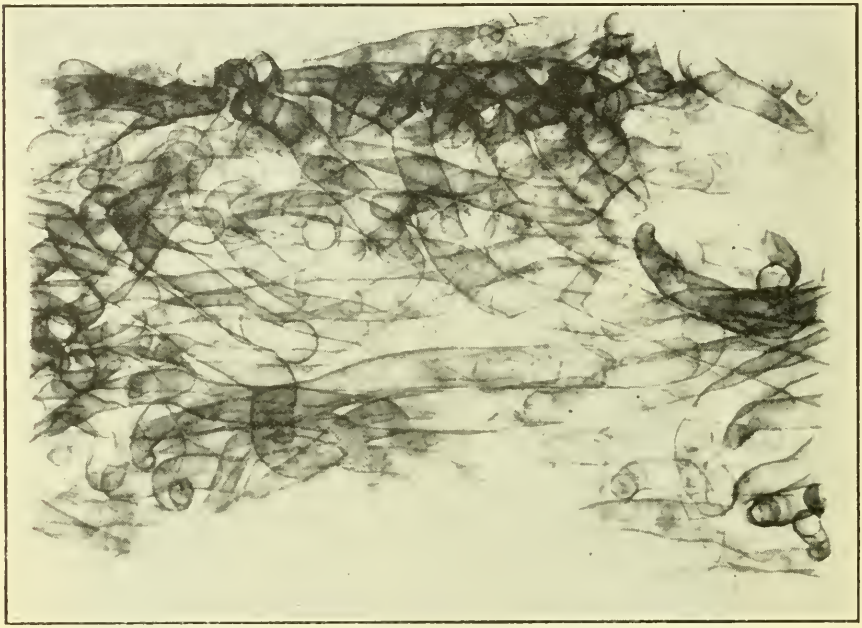


Fig. 13—X-Ray Photograph of Timber Attacked by Teredine Borers

Martesia (Fig. 14) more nearly resembles a clam in structure. The boring is done with the shells, as in the case of *Bankia* and *Teredo*, but the body of the animal is wholly enclosed within the shell instead of being drawn out into an elongated, worm-like form as in the other two genera. The borings made by *Martesia* are generally not over 2½ in. in length nor over an inch in diameter, while some species of *Bankia* are reported to reach a length of between 3 and 4 ft. with a diameter only slightly less than 1 in.

Martesia as well as *Teredo* and *Bankia* is equipped with a pair of siphons, one incurrent, the other excurrent. These siphons are muscular tubes of a length and appearance differing in the different species but performing the same functions for all of them. The siphons project into the water through the minute hole through which the animal entered the wood. By means of millions of microscopic hair-like structures (cilia), always beating in one direction, a current of water is drawn through the incurrent siphon and expelled through the excurrent. The water in its course through the body of the animal passes through the gills, as in other bivalve mollusks, where it gives up its oxygen to the blood, while the food materials are filtered out and carried to the mouth. A large part of the food of these

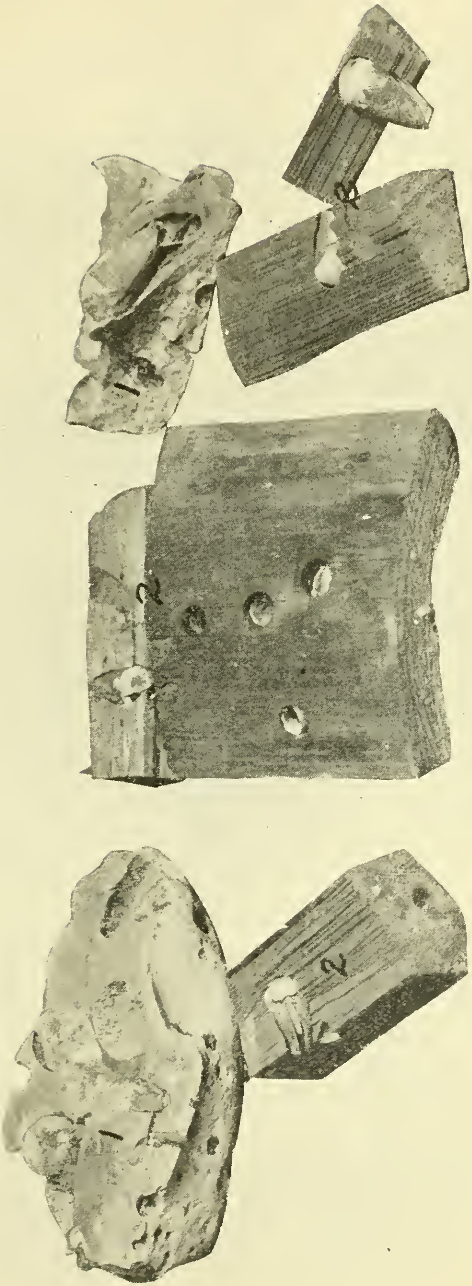


FIG. 14—*Martesia* IN WOOD AND *Pholas* IN ROCK

wood-boring Mollusca probably consists of the fine organic detritus and the microscopic plants and animals in the water, though recent investigations indicate that the wood fragments resulting from the boring may also be utilized as food. The water flowing out through the excurrent siphon carries with it the body wastes and the wood fragments rasped off by the shells.

When the animals are disturbed or the water conditions are for any reason unsatisfactory the siphons are retracted within the burrow.

The pallets are calcareous organs possessed by *Teredo* and *Bankia* but not by *Martesia;* they are conical, but aside from this common feature there is great variation in their shape and structure. When the siphons are extended the pallets are retracted, and when the siphons are retracted the pallets are pushed back toward the outside of the timber, tightly closing the entrance hole and protecting the animal within from the entrance of water of an unsatisfactory quality and from the attack of enemies.

The difference between the pallets of the two genera furnishes the easiest means of identification. The pallets of *Teredo* have various forms, depending on the species, but in all cases they consist of a stalk and spade or paddle-shaped blade convex on the outer and concave on the inner surface, while the pallets of *Bankia* (Fig. 15), also of shapes varying with the species, consist of the stalk and a segmented blade. The pallets of *Bankia* are generally much larger than those of *Teredo.*

Aside from a difference in the method of fertilization, the breeding habits and the life history of the various species are similar. In some species the spermatozoa are drawn in through the incurrent siphon and the eggs fertilized within the female, and in others the eggs are ejected through the excurrent siphon as the spermatozoa are, and the two meet in the water. The development into free swimming larvae of those species breeding by the latter method takes place in a few hours after fertilization, and in the case of those species in which the fertilization takes place in the gills of the female the larvae are ejected in the free swimming state, but it is probable that the development of the larva is slower than when fertilization takes place in the water.

From this point, the development of the animals is practically the same in the two genera. The larva has a bivalve shell into which the whole animal may be withdrawn for protection; a large swimming organ, the velum, by means of which it swims freely in the water; a long powerful foot by means of which it crawls actively over surfaces, and an internal organization like that of other larvae of the same group (Lamellibranchs, or bivalves).

The length of time between the commencement of larval development and the time when it is ready to attach itself to the timber and commence boring is supposed to be about 30 days.

Sigerfoos states as follows (Bull. of the Bureau of Fisheries XXVII, 1907, p. 193):

> "In association with their character of free development in the water the eggs of the shipworm are very small and very numerous. While they vary somewhat in size, they have an average diameter of somewhat less than 1/20 mm. (1/500 inch). Very large shipworms may lay great numbers of eggs at one time. In one case I estimated the number laid by a large female *Teredo dilatata* to be one hundred millions."

In describing the method of attachment of the larva, Sigerfoos states as follows:

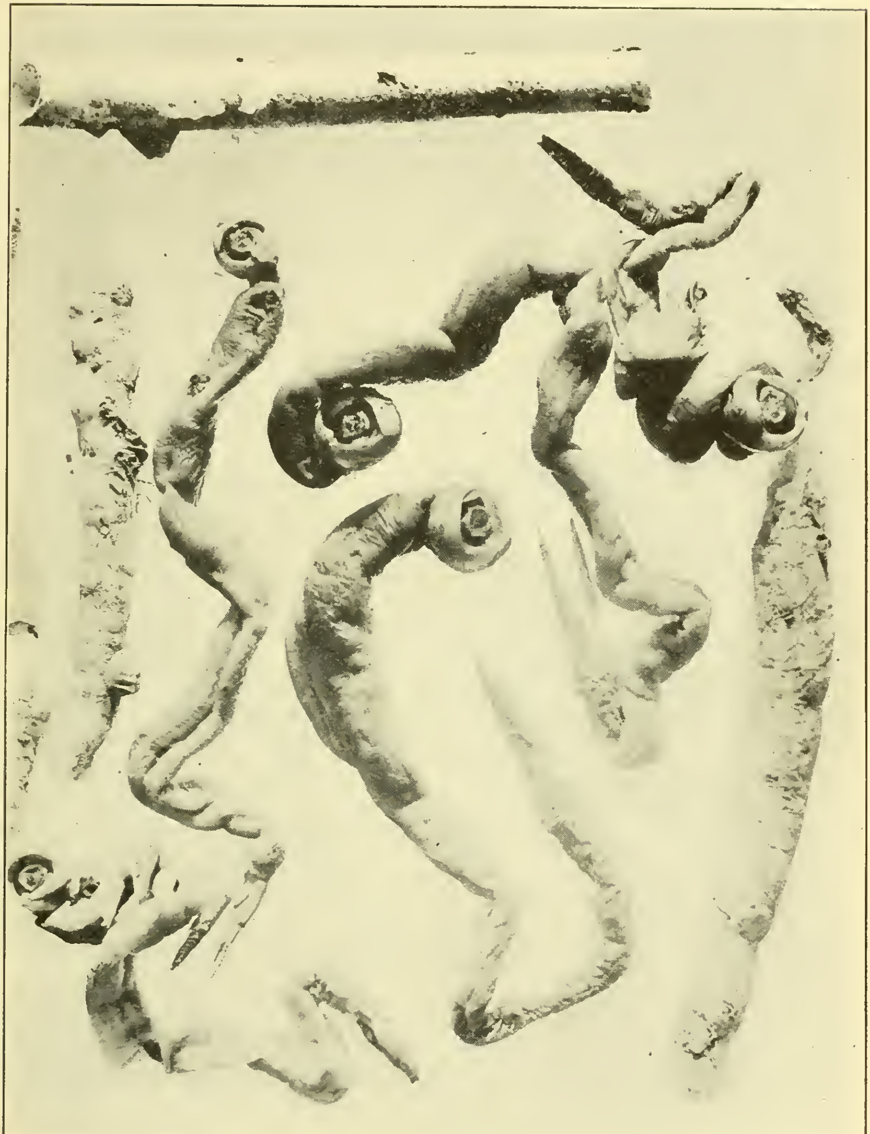


Fig. 15—Specimens of *Bankia* Removed from Burrows with Sections of the Burrow Casings.

"Throughout the summer (or at least from May till the middle of August) at Beaufort, if one examines fairly clean, unprotected wooden structures submerged in the water, very small bivalves will be found crawling actively over the surfaces. These are very minute and are easily recognized as shipworm larvae that have just settled upon the wood. The larva moves rapidly in search of a favorable place for attachment, and this is usually in some minute depression or crevice in the wood, though it may become attached to perfectly smooth surfaces. It seems to possess no organ of special sense for the purpose, and yet it is able to determine what places are favorable for its future life and to avoid those which are not. Once it has chosen a point for attachment it throws out a single long byssus thread, thus securing itself to the surface of the wood, and very soon loses its velum, so that it can no longer lead a free-swimming life. Once attached, the larva begins to clear away a place for its burrow by scraping away the surface of the wood with the ventral edges of its shell valves. Such small particles of wood and other substances as are thus collected are cemented together over the larva so as to form a sort of conical covering for protection. This formed, the further transformation of the larva into the small shipworm begins and progresses rapidly. The foot becomes a pestle-shaped organ which assists the shell in burrowing. The shell valves lose their power of opening at the ventral side and, by the development of knobs on the ventral and dorsal portions of both valves, are able to swing upon each other at right angles to the former direction. Meanwhile, because of the rapid growth of the valves on their ventral edges, the shell gapes at both anterior and posterior ends, for the protrusion of the foot in front and the siphons (and later the body) behind; and on the external surface of the valves at the anterior edges has been formed the first row of the small teeth which at this and later stages are the mechanical agents by which the animal bores into the wood. This transformation has taken place within two days from the time the larva has settled, and afterward the animal rapidly becomes an elongate shipworm, enlarging its burrow in the wood as it increases in size.

"The shipworm in its larval stages develops slowly, but once in the wood it grows with remarkable rapidity. During its free life most of its energies are devoted to active locomotion and development; after attachment it leads a protected sedentary life and its growth is correspondingly rapid. The newly attached larva is somewhat less than 0.25 mm. long. In 12 days it has attained a length of about 3 mm.; 16 days, 6 mm.; 20 days, 11 mm.; 30 days, 63 mm., and 36 days, 100 mm. It is thus seen that within two weeks from the time it has settled, the shipworm has increased hundreds of times in volume, and in five weeks thousands of times. Within two weeks it has developed its characteristic form. Even in a month specimens may contain ripe sexual elements, though normally these seem to be retained till larger quantities of spermatozoa and eggs are stored for extrusion at one time. I shall describe later what appears to be a change of sex from males to females, the male sex being developed in young specimens. I have found males four weeks old gorged with ripe spermatozoa, and in every way sexually mature.

"The ages of larger specimens I have been able only to estimate from the time the piles and other wooden structures from which they were taken had been in the water. In one case I took specimens of *Teredo dilatata* 4 feet long and an inch in diameter at the anterior end, from piles that had been in the water less than two years. This was in July, and in this case it seems the worms had entered the wood not earlier than the spring of the preceding year, and hence were little, if any, over a year old."

Teredo

Animals of this genus are found in all parts of the world, and the various species are reported to vary in length from 6 or 8 in. to 6 ft. In general the young develop within the female, and are extruded as free swimming larvae.

The capacity of the various species for destruction depends on the number of larvae per parent which survive, and the size to which the animals may grow. The number of larvae which survive in a given location is roughly proportional to the number carried by the adult female, and therefore, taken in connection with the size of the animals, an examination of the specimens gives a very fair approximation as to the potential destructiveness of the species.

Teredo (*Teredo*) *navalis* Linn., Syst. Nat., ed. 10, 1758, p. 651.

This species is probably the most widely distributed as well as one of the most destructive. It is reported to be present in salt water harbors in Europe from the North Cape to Italy, and perhaps less credibly as far east as the Black Sea.

The longest specimen found in the course of these investigations was 20 in. in length, found at Oakland, Cal., and the longest on the Atlantic Coast, found at Portsmouth, N. H., had a tube over 12 in. long with both ends eaten away by *Limnoria*.

Specimens of this species have been found in test blocks and timber from the harbors listed below, and a statement as to the degree of activity of this species in the various harbors will be found in the Harbor Reports:

Portsmouth, N. H.
Provincetown, Mass.
Newport, R. I.
Fall River, Mass.
Warren, R. I.
Providence, R. I.
Mystic, Conn.
New London, Conn.
Guilford, Conn.
Westport, Conn.
South Norwalk, Conn.
Fishers Island, N. Y.
New York Harbor, East River
New York Harbor, Lower Hudson River.
New York Bay.
Jamaica Bay, N. Y.
Fire Island, N. Y.
Point O'Woods, N. Y.
Point Pleasant, N. J.
Beach Haven, N. J.
Barnegat City, N. J.
Atlantic City, N. J.
Cape May, N. J.
Newport News, Va.
Norfolk, Va.
Beaufort, N. C.
Charleston, S. C.
Savannah, Ga.
Brunswick, Ga.
Fernandina, Fla.
Tampa, Fla.
St. Petersburg, Fla.
San Francisco, Cal.

Teredo (*Teredo*) *parksi* Bartsch (Plate III, Figs. 9-18). Proc. Biol. Soc. Washington, v. 34, p. 25-32.

The following is quoted from Dr. R. C. Miller's paper entitled "Wood Boring Mollusks From The Hawaiian, Samoan and Philippine Islands" (Cf. University of California Publications in Zoology, v. 26).

> This species was described by Bartsch (1921) from piling in Pearl Harbor. The shell is characterized by a broader anterior lobe and a consistently small auricle, characters which appear to exhibit less variability in this species than in most others. The pallets are readily distinguished by the long stalk and short, deeply excavated blade which is covered the greater part of its length by a dark epidermis. The blade is usually more deeply excavated on the outer than on the inner face, a character which is most accentuated in the Samoan specimens. The latter tend also to have more regularly shaped, straight-sided pallets. These characters, however, appear too variable to be of systematic importance. It is possible that further study may indicate a separate category for the Samoan specimens, but the material now at hand does not warrant such a step.
>
> *Teredo parksi* appears to be the dominant species in the islands, being present in the test blocks from all localities except Nawiliwili. The heaviest attack by this species occurred in Pearl Harbor. Blocks submerged here

September 1 showed considerable surface attack at the end of the month, and by the end of the second month a length of 8 cm. had been attained by the largest specimens. At the end of five months the blocks were thoroughly honeycombed and beginning to crumble as a result of the combined attack of *Teredo* and *Limnoria.* The rate of growth under normal conditions at this locality appears to be from 3 to 5 cm. a month during the first five months, at the end of which time the blocks were usually so crowded as to hinder or stop further growth. A burrow 18.5 cm. in length occurred in a block submerged five months at the United States Navy Coaling Plant, and a burrow 22.5 cm. long was found in a block submerged six months at Kuahua Island, these being the maximum lengths recorded.

This species is incubatory, and in Samoan waters becomes sexually mature within a few weeks after entering the wood. Specimens containing well developed larvae in the gills were found in blocks submerged only two months at Tutuila. Potts (1923) reports that rafts in the water only twenty-four days in Pago Pago Harbor contained shipworms which were producing free-swimming larvae; it is probable, although not certain, that he was dealing with this species. In Pearl Harbor *Teredo parksi* appears to mature more slowly and to reach a larger size, the difference doubtless being due to temperature conditions.

In Samoa *Teredo parksi* appears to breed uninterruptedly throughout the year, but in Hawaii the breeding activity, as indicated by settlement of larvae, reaches a maximum in August, September, and October, progressively decreases from November to March, and reaches a minimum, possibly ceasing altogether, in April.

Teredo furcillatus Miller (Plate IV, Figs. 19-23). Univ. Calif. Publ. Zool., v. 26.

Shell with the anterior lobe shorter and narrower than in *Teredo parksi,* and the auricle decidedly longer and broader. The shell is less highly polished and transparent, and the ridges of the anterior median area are more coarsely denticulated than in *T. parksi.*

Pallets with the stem long and the blade small, variable in shape, the distal portion deeply excavated on the outer and usually also on the inner face, athough the latter in some cases is only slightly notched. The most distinctive feature of the pallets is the absence of a dark periostracum, the distal portion of the blade being either light yellowish or perfectly white. The name is suggested by the resemblance of the pallets to a small two-tined fork (Latin *furcilla*).

The measurements of the type are: *shell,* height, 3.3 mm.; length, 3.4 mm.; *pallets,* length of blade, 1.7 mm.; width of blade, 1 mm.; length of stalk, 2 mm. The type, from Tutuila, Samoa, has been placed in the Museum of the California Academy of Sciences, San Francisco, as No. 1729. Paratypes have been placed in the collections of the Department of Zoology, University of California, the Academy of Natural Sciences, Philadelphia, and the United States National Museum.

Teredo furcillatus has occurred in limited numbers in the blocks from Tutuila and Honolulu Harbor. The longest burrow recorded was 6.7 cm. The species does not appear to be of much economic importance.

Teredo affinis Deshayes (Plate V. Figs. 29-33). Univ. Calif. Publ. Zool., v. 26.

Shell similar to that of *Teredo furcillatus,* but with the anterior lobe in general narrower and the auricle broader, differences which have been fairly constant in all the specimens examined.

Pallets with a long, slender stalk; blade consisting of a short, urn-shaped, calcareous base, surmounted by a dark brown, chitinous distal portion, wholly uncalcified, and of very irregular shape. In specimens considered typical the distal portion consists of a narrow, elongate, cupped median extension, very deeply excavated on the outer, less deeply on the inner face; and further cut away on each side nearly to its juncture with the calcareous base, where the chitinous portion is spread out abruptly and slightly excavated to form two shallow lateral cups. As a result of wear the median

extension may be excavated nearly to the base within as well as without, so that the pallet appears to end in two slender leathery fingers. The lateral excavations are usually unequal, and one or both may be entirely lacking. The calcareous base is cut off abruptly at its juncture with the distal chitinous portion.

This species was described by Deshayes (1863) from Reunion Isle. Notwithstanding the irregularity in the form of the pallets, the characteristic leathery distal projections enable them to be recognized almost at a glance. But the chitinous portion rather readily comes free of the calcareous base, which then has a deceptive appearance of completeness, and might be mistaken for a pallet of some other species.

The test board at Nawiliwili was placed February 1, 1923. In the earlier blocks *Teredo affinis* predominates, and is very destructive; but in the blocks placed after September it is almost entirely replaced by *Teredo bartschi* and *Teredo diegensis.* A few specimens of *T. affinis* have been found in the blocks from Honolulu Harbor.

Teredo samoaensis Miller (Plate IV, Figs. 24-28). Univ. Calif., Publ. Zool., v. 26.

Shell similar to that of *Teredo furcillatus*, but generally more transparent, and with a similar auricle. Interiorly the shell is characterized by a very broad, irregular apophysis, which is a useful, although not infallible guide in the identification of the shell.

Pallets with a stalk of medium length and a long tapering blade, which is divided into two distinct portions. The basal portion, comprising about one-half the length of the blade, is broadly ovate and calcareous; the distal portion consists of a narrower, nearly straight-sided, more or less completely calcified semicylinder, flattened on the inner face, slightly cupped at the extremity. At the juncture of these two elements the pallet is encircled by a band of brown epidermis, which some times more or less completely envelops the distal portion.

The type specimen, from Tutuila, Samoa, is No. 1730, Museum of the California Academy of Sciences, San Francisco. Paratypes have been placed in the collections of the Department of Zoology, University of California, the Academy of Natural Sciences, Philadelphia, and the United States National Museum. The measurements of the type are: *shell*, height, 3.8 mm.; length, 3.8 mm.; *pallets*, length of blade, 2.9 mm.; width of blade, 1.3 mm.; length of stalk, 2.1 mm.

This species has been found only in Samoa, where it occurred commonly in the blocks from a board placed in November, 1923. This board was lost before adequate data were secured, and a second board placed the following June was not attacked at all by this species.

Teredo trulliformis Miller. (Plate V, Figs. 34-37). Univ. Calif. Publ. Zool., v. 26.

Shell with a greatly reduced auricle, which is so fused with the posterior median portion that the boundary between the two can scarcely be detected on the exterior surface. Interiorly the auricle overlaps the posterior median portion a little distance, and its anterior edge can be distinguished, but does not form a shelf with a cavity behind it as it does in all of the foregoing species.

Pallets with a short, broad blade, and a stalk of medium length which, instead of tapering toward the end, becomes gradually expanded, like the handle of a trowel (Latin *trulla*). The distal portion of the blade is covered by a grayish or brownish epidermis, and the extremity is characterized by a shallow crescent-shaped excavation.

The posterior end of the tube is divided by a calcareous partition, forming two siphonal openings.

The measurements of the type are: *shell*, height, 3.4 mm.; length, 3.2 mm.; *pallets*, length of blade, 1.8 mm.; width of blade, 1.2 mm.; length of stalk, 1.3 mm. The type, from Honolulu Harbor, is No. 1731, Museum of the California Academy of Sciences, San Francisco. Paratypes are in the

collections of the Department of Zoology, University of California, the Academy of Natural Sciences, Philadelphia, and the United States National Museum.

This species occurs commonly in the blocks from Honolulu Harbor, and somewhat rarely in the blocks from Pearl Harbor and Nawiliwili. The longest burrow recorded measured 9 cm.

Teredo (*Teredora*) *thomsoni* Tryon. Proc. Acad. Nat. Sci. Philadelphia. Ser. 2; v. 7, 1863, pp. 280, 281 pl. 2; figs. 3-5.

This species is of large size, rapid growth and quite destructive. Specimens have been found in test blocks from:

Channel Five, Fla.
Key West, Fla.
St. George, Bermuda.

Teredo (*Teredora*) *panamensis* Bartsch. U. S. Natl. Mus. Bull. 122, 1922, p. 34 pl. 27, figs. 3 and 4; pl. 35 fig. 2.

This is a very destructive species of medium size and has been found only at Coco Solo, C. Z., though it is credibly reported to be present in other harbors in the vicinity of the Canal Zone where no specimens were collected by this Committee.

Teredo (*Psiloteredo*) *dilatata* Stimson. Proc. Bost. Soc., Nat. Hist., v. 4, 1851, p. 113.

A few specimens of this species were found at York Harbor, Me., and Provincetown, Mass., only. It reaches considerable size, but so far as the present investigation shows does not seem to be of great economic importance from the standpoint of damage to harbor structures.

Teredo (*Psiloteredo*) *sigerfoosi* Bartsch. U. S. Natl. Mus. Bull. 122, 1922, pp. 39 and 40, pl. 28 fig. 2; pl. 36 fig. 1.

Specimens of this species were found only at Beaufort, N. C., and Charleston, S. C. It is a very destructive species and reaches considerable size.

Teredo (*Lyrodus*) *bipartita* Jeff. Ann. Mag. Nat. Hist. ser. 3, v. 6, 1860.

Specimens have been found only at Channel Five, Fla., and Agars Island, Bermuda. The number of larvae found in the adult females was small, and the species is not, so far as is indicated by these investigations, of much economic importance.

Teredo (*Teredothyra*) *dominicensis* Bartsch. U. S. Natl. Mus. Bull. 122, 1922, pp. 23-24, pl. 21, fig. 2; pl. 33, fig. 1.

Teredo (*Teredothyra*) *atwoodi* Bartsch. Proc. Biol. Soc. Wash., v. 36, pp. 97-98

It has been found impossible to separate these two species in the examination of the large number of specimens available. These species are very destructive, and have been found in the following harbors:

Matanzas, Cuba.
Guantanamo, Cuba.
San Juan, Porto Rico.
Fajardo, Porto Rico.
San Pedro de Macoris, S. D.
Santo Domingo, S. D.
Christiansted, V. I.

Teredo (*Zopoteredo*) *clappi* Bartsch. Proc. Biol. Soc. Wash. N., 36, 1923, pp. 96-97.

This very destructive species has been found in the following harbors:

Channel Five, Fla.
Key West, Fla.
St. George, Bermuda.
Bars Bay, Bermuda.
Fajardo, Porto Rico
Guantanamo, Cuba.
Port au Prince, Haiti.
San Pedro de Macoris, S. D.
Christiansted, V. I.
Coco Solo, Canal Zone.

Teredo (*Teredops*) *diegensis* Bartsch. U. S. Natl. Mus. Bull. 122, 1922, pp. 29-30; pl. 22, fig. 3; pl. 34, fig. 3.

Specimens of this species have been found only in the Pacific Coast harbors of San Francisco, Los Angeles, Long Beach and San Diego. In activity it resembles *Teredo navalis* and is somewhat smaller, but is of much greater relative importance in San Diego than in San Francisco.

According to Dr. Miller the specimens from the Pacific Islands differ from typical *T. diegensis* in having the ridges on the shell more close set, and the epidermis of the distal portion of the blade of the pallets more transparent, so that the outline of the oval calcareous portion within can be plainly seen.

> "In preserved specimens that we have received from Nawiliwili the distal epidermis is of amber clearness; but the dried pallets have the epidermis darker and more opaque, so that they are not distinguishable from those of specimens from the California coast." (Univ. Calif. Publ. Zool., V. 26, No. 7.)

In addition to the above previously described species, the examinations of test blocks and timber have shown the existence of a number of previously undescribed species. Some of these have been described by the biologists of the Committee, and others will be described in later publications. Those for which descriptions have not yet been prepared have for convenience been designated by letters or numbers in order to permit a statement of their description.

Teredo (*Teredo*) *bartschi* Clapp (Plates VI, VII). Bost. Soc. Natl. Hist. v. 37, No. 2, 1923, pp. 31-38; pl. 3-4.

> Type specimen No. 45301, Museum of Comparative Zoölogy, from Port Tampa, Fla. Additional specimens from the type locality are also in the United States National Museum; the Academy of Natural Sciences, Philadelphia; the American Museum of Natural History, New York; and the Museum of Comparative Zoölogy, Cambridge, Massachusetts (No. 45302).
>
> Description—Shell subglobular, milk-white, covered with a thin, deciduous, light horn-colored periostracum. The anterior portion of the shell joins the anterior median area in a gentle curve, the ventral edge making an angle of approximately 100°. Exteriorly, the anterior portion is marked with minutely denticulated ridges. At the ventral edge, these ridges are one-half as wide as the intervening spaces, the spaces becoming irregularly wider dorsally, where the ridges are one-fourth as wide as the spaces. Beginning at the ventral edge there are 15 of these ridges in one millimeter. On that portion of the posterior ridge near the anterior median area, there are 80 denticles to the millimeter. These denticles have sharp, slightly curved points, supported by round blunt bases (Pl. VII, Fig. 46). The anterior median area, at a point opposite the ventral edge of the anterior area, occupies slightly less than one-third of the entire median area, and bears the usual denticulate ridges, there being 15 of these ridges to 0.5 mm. in a line continuous with the ventral border of the anterior area. In the type there are 16 of these ridges at this point, separated only by very finely incised lines. Each ridge bears closely crowded, broad denticles, of which there are 27 to the millimeter on the anterior ridge in the vicinity of its junction with the ventral ridge of the anterior area (Pl. VII, Fig. 47). The ventral ends of these ridges bend back over the anterior median area at an angle of 45°, becoming gradually narrower and disappearing in the middle median area; or they may be only discernible as faint lines of growth. The middle median area is the complement of the anterior median area, being narrow dorsally and broad ventrally. At that portion of the shell directly opposite the ventral edge of the anterior area, the middle median area is slightly narrower than the anterior median. The anterior third of this area is convex, and roughened by the continuation of the ridges of the anterior area as growth lines; the posterior two-thirds is concave and smooth. The

posterior median area is smooth and merges imperceptibly into the auricle, which is large and transparent.

Interiorly, in the left valve, a short, broad, curved and pointed hinge-tooth arises from directly beneath the umbone. The blade is two-thirds the length of the shell, slightly curved, broad, and reflected posteriorly, in the middle. Ventral knob large, of the same width as the ventral portion of the middle median area from which it arises; it is supported anteriorly by a delicate wall entirely free posteriorly and ventrally. Internal shelf of the auricle strong and well marked.

Pallets of the type of *Teredo navalis* Linné. Stalk slightly longer than the blade. The lower half of the blade is calcareous, broad, flat on the inner, convex on the outer face, somewhat abruptly contracted at the juncture with the stalk, and enveloping the stalk with a short thin sheath. In the upper half of the blade, the calcareous portion is covered by a light yellowish horn-colored periostracum, the exterior face of which is more deeply cupped than the interior. Through the semi-transparent periostracum the calcareous portion of the blade can be seen to continue distally, in an irregular form somewhat similar to a broad hourglass, with a deep sinus on either side.

At the posterior end of the tube, a short distance from the external opening, are two thin, sharp longitudinal ridges, or lamellae, arising from opposite sides of the internal wall and nearly meeting at the center. When in position, the broad surface of the blade of the pallet is at right angles to these lamellae (Pl. VI, Fig. 40). At the external opening of the tube, on each side, between the lamellae, is a deep sinus.

The measurements of the type are: shell, height, 4 mm.; length, 4.2 mm.; pallets, total length, 5 mm.; stalk, 3 mm.; width of blade, 1.2 mm.

The dimensions given for the shell are those of a superimposed rectangle, exactly containing the shell, with the sides parallel to a line drawn between the centers of the dorsal and ventral knobs.

I take great pleasure in naming this species for Dr. Paul Bartsch of the United States National Museum.

Teredo bartschi belongs to the group of which *Teredo navalis* is the type. It may be distinguished from the other species of that group by the peculiar construction of the pallets. In *Teredo bartschi* the distal half of the blade is transparent, showing the internal calcareous cone, while in *T. morsei*, *novangliae*, *beaufortana*, and *T. beachi* of Bartsch, all but the distal extremity of the blade is calcareous and opaque. The dimensions of the pallets of the type specimens of the above species also show that *T. bartschi* differs in having the blade much shorter than the stalk.

	TOTAL LENGTH OF PALLET	STALK	BLADE
Teredo beachi	5.5 mm.	2.0 mm.	3.5 mm.
novangliae	5.0	1.7	3.3
morsei	5.1	1.7	3.4
beaufortana	5.2	2.0	3.2
bartschi	5.0	3.0	2.0

It will be seen from the above table that the dimensions of the pallets of the first four species listed are very similar to one another and very different from those of *T. bartschi*. When dry, the pallets assume a very different but characteristic appearance. The distal chitinous portion acquires the shape of the internal calcareous portion which it surrounds, while the lower portion is drawn in laterally to fill the sinus in the calcareous part and the cup is made nearly flat (Pl. VI, Fig. 38). The internal partitions or ridges of the tube also serve to distinguish this species from any previously described species of Teredo *s.s.* on this coast. When the pallets are forced into the posterior end of the tube, the external convex surfaces of the blades, coming in contact with these sharp ridges, are forced in, pressing the internal flattened faces of the blades more closely together, and thus closing the external opening more effectually.

The embryos within the parent are reddish purple in color, and are frequently found in parents having a total length of only 20 mm. When

ready to be expelled from the parent, the shell of the embryo is nearly circular in outline, approximately 0.27 mm. in height and 0.25 mm. in length. It is nearly transparent, light horn-colored, excepting in the vicinity of the edge of each valve, particularly that portion near the umbone, where there is a narrow band of reddish-purple color. When viewed in bulk, this color predominates. Directly beneath the umbone is a strong flat hinge-plate, with from four to six irregular, faint, incised lines.

The shell differs most constantly from that of the species described by Dr. Bartsch as *Teredo morsei* (Bartsch, 1922, p. 21), in the shape of the auricle. In *T. morsei* the height of the auricle is greater than the length, and the outline is subangular. In *T. bartschi* the auricle is produced posteriorly, the length being equal to the height, and the outline semicircular. The great variation in the shell characters of Teredo and the objections to using these characters for distinguishing species, have been well described by Dr. Miller (1922, p. 309), who has called attention particularly to the variation in the auricle.

The destruction caused by this species is considerable. Test blocks from Port Tampa, Fla., submerged for twelve weeks, contained specimens with a tube length of 125 mm. Specimens from wood submerged for a longer period frequently attain a length of 200 mm. Test blocks submerged for eight weeks are often completely honeycombed (Pl. VI, Fig. 41).

This species has been found at the following locations in the blocks placed by the Committee on Marine Piling Investigations. With the exception of Cedar Keys, Fla., it has always been found in company with *Bankia gouldi.*

SOUTH CAROLINA: Charleston. Rare. About one specimen of *Teredo bartschi* to 50 *Bankia gouldi.* No attempt was made by the embryos of this species to enter wood at this locality later than October 15 in 1922.

GEORGIA: Brunswick. Very rare. *Bankia gouldi* plentiful.

FLORIDA: Fernandina. Rare. Attack occurring as late as November 15 in 1922.
Seddon Island. Rare.
St. Petersburg. Rare. Attack continuing to December 15 in 1922.
Port Tampa. Common.
Fort Dade. Common. No embryos in wood placed in water later than December 15, 1922.
Cedar Keys. Common. No attack at this locality later than November 15 in 1922.

MISSISSIPPI: Pascagoula. Not common.
Gulfport. Rare.

LOUISIANA: Port Eads. Common; 90% of the shipworm attack due to *Teredo bartschi*, 10% to *Bankia gouldi.* No embryos entering the wood later than January 1, 1923.

TEXAS: Galveston (Fort Point). Not common; 10% of the shipworm attack due to *Teredo bartschi*, 90% to *Bankia gouldi.* Specimens received from this locality, in blocks submerged ten weeks, contained well-developed embryos in parents with a total length of 25 mm.
Galveston (Pier 18). Common; 90% *Teredo bartschi*, 10% *Bankia gouldi.* Specimens with 50-mm. tubes and containing embryos, were received from this locality in wood which had been submerged less than twelve weeks.
Galveston (Pier C, Southern Pacific Railway). Common. A block submerged six weeks contained many specimens with 40-mm. tubes.
Baytown. Very rare. In many hundred shipworms found in test blocks from this locality, but one *Teredo bartschi* occurred.
Aransas Pass. Rare.
Corpus Christi. Common.

It will be noticed that this species has not been found in southern Florida, and this also is true of *Bankia gouldi.* The two species have a continuous

distribution from South Carolina to Texas, excepting only the southern tip of Florida. Blocks from test boards at numerous stations in southern Florida contain many shipworms of several species, but in no case has an example of *Teredo bartschi* or *Bankia gouldi* been found south of Fernandina on the east coast or Tampa on the west coast. This distribution will be discussed in a later paper.

Dr. Miller found that

> "Specimens of a *Teredo* prevalent in the later blocks from Nawiliwili compare closely with paratypes of this species which I have received from Mr. Clapp. This species occurs numerously in the blocks placed after September, and somewhat sporadically in the earlier blocks." (Univ. Calif. Publ. Zool., v. 26, No. 7.)

Teredo (*Teredo*) *portoricensis* Clapp (Plate VIII, Figs. 48-54). (Trans. Acad. Sci. of St. Louis, v. XXV.)*

Shell, subglobular, white, covered with a transparent colorless, periostracum. The juncture of the anterior, with the anterior median area, clearly marked by a broadly curved, slightly incised line. The ventral edge of the anterior area, forming an angle of about 100° with the anterior edge of the anterior median area. Externally the anterior area with the usual, denticulated ridges, the ventral posterior portion, with the ridges of about the same width as the intervening spaces. Dorsally the ridges are one-fourth as wide as the spaces between them. Beginning at the ventral posterior edge there are eight of these ridges to the millimeter, each ridge bearing approximately seventy denticles to the millimeter (Pl. VIII, Fig. 48). The anterior median area, at a point opposite the ventral edge of the anterior area, occupies one-quarter of the entire median area. There are on this area, in a line continuous with the ventral edge of the anterior area, denticulated ridges averaging in width twenty-five to the millimeter. There are in the type, eleven of these ridges, which bear the usual broad denticles, there being twenty-eight to the millimeter (Pl. VIII, Fig. 49). The ventral ends of these ridges can be clearly seen continuing as sharp growth lines over the entire median area, becoming less distinct on the auricle. The middle median area is milk white in contrast to the semi-transparent anterior median area, and is separated from the anterior median area by a thin, narrow, transparent band. The posterior median area is milk white and occupies one-half of the entire median area. The auricle is semi-transparent, showing more or less irregular growth lines and with the periostracum thicker than elsewhere on the shell.

Internally, in the left valve, a short, broad, flat hinge tooth, directly beneath the umbone. The blade slightly more than one-half the length of the shell, of about the same width for its entire length, the lower half reflected posteriorly. The ventral knob large. The internal shelf of the auricle well marked.

Pallets (Plate VIII, Fig. 50) of the type of *Teredo navalis* Linné. The stalk of about the same length as the blade, and merging with it in a gradual curve. The lower half of the blade white, and, seen through the transparent chitinous portion of the upper half with the calcareous part slightly cupped, the outer portion extending farther distally than the inner. The upper half entirely composed of transparent, yellowish horn colored periostracum. Deeply cupped distally for more than half its length, the outer surface being slightly less deeply cupped than the inner, and with a narrow, deep sinus at the center.

The posterior end of the tube, with two short, narrow, low ridges, arising from opposite sides of the internal wall, these ridges continuing posteriorly beyond the shelly portion of the tube as sharp points.

---

*Consult W. F. Clapp, Bost. Soc. Nat. Hist., 1923, vol. 37, No. 2, p 31, Fig 1, for a description of the test blocks used by the Committee on Marine Piling Investigations. Also, for notes regarding the nomenclature used in the description of the various characters of the shell and pallets, and for references to recent literature on the subject.

I am deeply indebted to Prof. S. C. Prescott of the Massachusetts Institute of Technology, Cambridge, Mass., for laboratory facilities and for other assistance.

The type specimen (Mus. Comp. Zoöl. No. 45303) (Plate VIII, Figs. 51-54) is from San Juan, Porto Rico. Additional specimens from the type locality are also in the U. S. National Museum.

The measurements of the type are:

Entire length of tube, 40 mm.
Shell: Height, 3.2 mm. Length, 3.1 mm.
Pallets. Length, 3.8 mm., divided equally between blade and pallets. Width of blade, 0.8 mm.

Teredo portoricensis is most closely related to *Teredo bartschi* Clapp. The variation in the shell characters in each species is so great, that only very slight constant differences can be seen. The normal shell of a mature specimen of *T. portoricensis* is smaller than that of *T. bartschi.* The length of the apophysis constantly proportionately less. The partitions in the tube, while always present, are much lower and shorter than in *T. bartschi.* The pallets most closely resemble those of *T. bartschi,* but constantly differ in having the blade longer and narrower, the juncture of the blade and pallet hardly perceptible, and the basal portion of the blade more gradually and narrowly expanded. Seen through the periostracum, the calcareous portion of the blade of the pallet of *T. bartschi* is cone shaped, while that of *T. portoricensis* is the opposite, deeply cupped at the center. In *T. portoricensis,* the periostracum on the outer face of the blade is less deeply cupped than that on the inner, while in *T. bartschi* the opposite is true.

This species has been found in the test blocks placed by the Committee on Marine Piling Investigations, National Research Council, at the following locations: Guantanamo, Cuba; San Pedro de Macoris, Santo Domingo; Port au Prince, Haiti; San Juan, Porto Rico; St. Thomas, Virgin Islands; Coco Solo, Panama; and one specimen from Key West, Fla.

At Guantanamo, Cuba, wood placed in the water on April 10 contained specimens 10 mm. in length on May 10; 60 mm. in length on June 10, and 75 mm. in length July 10.

At Port au Prince, Haiti, wood submerged December 1, 1922, contained on January 1, 1923, many 5 mm. specimens; January 15, 30 mm. specimens, and on February 1, 30 mm. specimens with the gills well filled with many fully developed embryos. Wood placed in the water at this location on June 1, 1923, while well filled with several other species of shipworms, contained no specimens of *T. portoricensis* as late as September 3, 1923.

At San Pedro de Macoris, Santo Domingo, wood submerged December 1, 1922, contained 20 mm. specimens on February 1, 1923, many with well developed embryos.

At San Juan, Porto Rico, wood placed March 20, 1923, contained on May 30, 40 mm. *T. portoricensis* with embryos.

At St. Thomas, Virgin Islands, wood placed April 1, 1923, contained many 30 mm. specimens on June 1.

At Coco Solo, Panama, wood submerged December 4, 1922, contained many 30 mm. specimens on January 19, 1923, and on February 19 many specimens with well developed embryos in the gills.

It can be seen from the above records that this species may grow to be 60 mm. in length, in a period of two months or at a rate of approximately 1 mm. a day, and that specimens with a total tube length of but 20 mm. may possess well developed embryos within the gills. Its rapid growth and early sexual maturity render it one of the species most frequently found in the West Indies, and the destruction caused by it is considerable.

Teredo (*Teredo*) *batilliformis** Clapp (Plates IX, XI,) Proc. Amer. Acad. Arts and Sci., v. 59, No. 12. (Contrib. Bermuda Biol. Sta. for Research, No. 143.)

Shell subglobular, white, covered with a thin horn-colored periostracum. The anterior area joining the anterior-median area in a slightly curved incised line. The ventral edge of the anterior area curving downward and

*From *batillum*, a shovel, referring to the shovel-shaped pallet, a name suggested by Dr. Mark.

backward, but forming with the anterior edge of the anterior-median area an angle of only slightly more than 90°.

Externally, the anterior area with the usual denticulate ridges. These ridges are one-half as wide as the intervening spaces. Beginning at the ventral posterior edge there are ten of these denticulate ridges to the millimeter, each ridge bearing eighty denticles to the millimeter (Plate XI, Fig. 67). The width of the anterior-median area, at a point opposite the ventral edge of the anterior area, slightly less than one-third that of the entire median area. The denticulate ridges on this area average twenty-six to the millimeter, counted along a line extending from the ventral edge of the anterior area perpendicular to the ridges. In the type specimen there are fifteen of these ridges, each bearing about twenty-eight denticles to the millimeter (Plate XI, Fig. 68). The denticles on the ventral ends of these ridges end abruptly where the ridges, as faint growth lines, bend backward over the anterior portion of the middle-median area. The posterior portion of the middle-median area, thin, transparent, slightly concave. The posterior-median area opaque, milk-white, considerably more than half as wide as the entire median area; its posterior half marked by narrow deeply incised growth lines, dividing this part of the shell into regularly spaced broad ridges. The auricle small and semi-transparent, excepting the outer edge, which is milk-white. Where the anterior margin of the auricle meets the posterior-median area, the latter presents a narrow shoulder, but this does not prevent tracing, on the auricle, the growth lines, which there appear as narrow, transparent, concentric threads.

Internally, the left valve with a very large broad hinge-plate. In both valves the blade two-thirds of the length of the shell, thin, the dorsal part narrow, the middle and ventral portions broadened and slightly reflected posteriorly. The ventral knob large. The juncture of the anterior area with the anterior-median area marked by a broad, thick, transparent callous. The auricle extending over the posterior-median portion in a broad, thick, opaque, callous, ending in an abrupt ridge, but lacking any trace of a shelf or overhang.

Pallets (Plate IX, Figs. 59, 60) with a broad, nearly square blade, which envelops with a thin sheath a long, very slender stalk. The proximal portion of the blade white, arising from the stalk in an abrupt curve. The calcareous portion extends to the extreme distal end of the blade, the distal two-thirds of which is covered with a yellowish-horn-colored periostracum. The inner face of the blade flat, the distal edge nearly straight. The outer face slightly convex, its distal portion with a broad shallow depression.

The posterior end of the shelly tube with two long, narrow ridges, arising from opposite (lateral) sides of the internal surface; the wall greatly thickened at the base of these ridges and continuing beyond the rest of the shelly portion of the tube as sharp points.

The type specimen (Mus. Comp. Zoöl. No. 45305) is from St. George, Bermuda.

The measurements of the type are:

Shell: Height 4 mm.; length 3.75 mm.
Pallets: Entire length 3.7 mm.; length of stalk 2.1 mm.; of blade 1.6 mm.; width of blade 1.3 mm.

It is very difficult to separate the *shell* of *Teredo batilliformis* from that of other closely related species of *Teredo*. From *Teredo portoricensis* it may usually be distinguished because possessing a proportionately larger anterior area. The ventral edge of the auricle forms a less abrupt angle with the posterior-median area than in *Teredo portoricensis*. The broad flat hinge-plate is much larger, and the blade proportionately longer. The juncture of the auricle with the posterior-median area is less well marked. The internal ridges of the posterior end of the tube are considerably longer than is usual in *Teredo portoricensis*.

The pallets are very different from those of any previously described species, the delicate stalk and the broad, squarish blade being so dissimilar to those of other species of the subgenus *Teredo* that I place this species here with some doubt.

Teredo batilliformis has been found only at Bermuda. It has occurred at frequent intervals in test-blocks at all four of the stations (Agar's Island, Bar's Bay, Ireland Island and St. George) established there. A test-block submerged at Agar's Island in August, 1922, and removed January 1, 1923, contained, among others, one specimen with a tube 35 mm. in length and holding in the gills about one hundred fully developed embryos. The first specimens to be found appeared in the test-blocks at all four stations simultaneously in the latter part of December. None attained a total length of more than 60 mm., and no specimens contained more than one hundred embryos in the gills.

Teredo (Teredo) spp. D. E. L., Clapp.

These tentative species very closely resemble each other, and while a rather wide individual variation has been found, further study may show that they are one species. Their resemblance to *Teredo (Teredo) parksi* is very close, and further study may show that all three belong to this species. The distribution is as follows:

"D"

Key West, Fla.

"E"

Ireland Island, Bermuda.
Guantanamo, Cuba.
San Juan, Porto Rico.
Fajardo, Porto Rico.
Port au Prince, Haiti.
St. Thomas, Virgin Islands.
Coco Solo, Canal Zone.

"L"

St. George, Bermuda.
Ireland Island, Bermuda.
Bar's Bay, Bermuda.
Agar's Island, Bermuda.

Teredo (Psiloteredo) sp. Q Clapp.

This undescribed species is of wide distribution in Gulf and Caribbean waters, and is of importance from a standpoint of destructiveness. Specimens have been found in the test blocks from:

Key West, Fla.
Tampa Bay, Fla.
Pensacola, Fla.
Mobile Bay, Ala.
Pt. Isabel, Tex.
Guantanamo, Cuba.
Fajardo, Porto Rico.
Aux Cayes, Haiti.
Puerto Plata, San Domingo.
St. Thomas, Virgin Islands.
Coco Solo, Canal Zone.

Teredo (Psiloteredo) sp. W Clapp.

This species has been found only at Port au Prince, Haiti, and is of little economic importance.

Teredo (Lyrodus) sp. G Clapp.

This undescribed species is of considerable economic importance, although it does not appear to reach great size. Specimens have been found at the following locations:

Matanzas, Cuba.
Guantanamo, Cuba.
Arecibo, Porto Rico.
San Juan, Porto Rico.
Mayaguez, Porto Rico.
Fajardo, Porto Rico.
San Pedro de Macoris, San Domingo.
Puerto Plata, San Domingo.
Port au Prince, Haiti.
Aux Cayes, Haiti.
St. Thomas, Virgin Islands.
Coco Solo, Canal Zone.

Teredo (Lyrodus) sp. J Clapp.

This undescribed species is very closely allied to sp. G, and may be found after further study to be the same. Specimens have been found at Aransas Pass, Corpus Christi and Point Isabel, Tex.

Teredo (*Zopoteredo*) *somersi** Clapp (Plates X, XI) Proc. Amer. Acad. Arts and Sci., v. 59, No. 12. (Contrib. Bermuda Biol. Sta. for Research, No. 143.)

Shell subglobular, white, covered with a transparent, colorless or very light horn-colored periostracum. The anterior area with the usual denticulate ridges. The juncture of the anterior with the anterior-median area marked by a curved, slightly incised line. The ventral edge of the anterior area forming an angle of 100° or more with the anterior edge of the anterior median area. On the ventral posterior portion of the anterior area the denticulate ridges of approximately the same width as the intervening spaces. Dorsally, the intervening spaces only a little wider than the denticulate ridges. At the ventral portion there are twelve of these ridges to the millimeter, each ridge bearing one hundred and ten minute denticles to the millimeter (Plate XI, Fig. 69). The anterior median area occupies slightly more than one-third of the entire median area. The broadest portion of this area—at the level of the ventral edge of the anterior area—bears seventeen of the usual denticulate ridges, which average thirty-five to the millimeter; the anterior ridge bears thirty-two denticles to the millimeter (Plate XI, Fig. 70). The posterior-ventral ends of these ridges can be faintly seen as growth lines passing backward over the middle-median area, quickly disappearing on the posterior-median area, which is nearly smooth. The auricle is small, its outline nearly semi-circular and its juncture with the posterior-median area perceived only with difficulty.

Interiorly, there is the usual broad, flat hinge-plate in the left valve directly beneath the umbone. The apophysis, curving downward and backward for slightly more than one-half the length of the shell, narrow and thin, excepting at its extreme ventral portion, where it is considerably broadened. The concave surface of the blade reflected posteriorly. The juncture of the auricle with the posterior-median area having no trace of a shelf, but marked by a broad, thickened area, with a narrow groove at its anterior edge.

Pallets (Plate X, Figs. 65, 66) very strong and solid. The stalk short, thick, opaque-white, equal in length to the blade. The juncture of the stalk with the sheath of the blade abrupt and well marked, owing to the much larger diameter of the sheath. The blade calcareous, white, expanding from the stalk by a broad regular curve, the distal half covered by a nearly opaque, heavy, smooth, closely fitting periostracum of light horn-color. Only the chitinous horns at the extreme distal end of the blade lacking the calcareous substance. The sides of the blade converging slightly distally. Inner surface of the blade very slightly concave, outer surface convex, deeply cupped at the distal end, the outer face somewhat less deeply cupped than the inner.

The posterior end of the tube with a very short, thin, horizontal partition, dividing the tube into equal parts. The tube greatly thickened on each side at the base of the partition.

The type specimen (Mus. Comp. Zoöl. No. 45304) is from Ireland Island, Bermuda. There are also in the U. S. National Museum additional specimens from the type locality.

The measurements of the type are:

Shell: Height 3.2 mm.; length 2.8 mm.

Pallets: Length 2.9 mm., divided equally between blade and stalk; width of blade at widest portion 1 mm.

The shell of *Teredo somersi* can be separated from that of *Teredo* (*Zopoteredo*) *clappi* Bartsch (1923a, p. 96) only with great difficulty. I have placed this species in the subgenus *Zopoteredo* because it has at the juncture of the auricle with the posterior-median area the structure typical of that subgenus. From *Teredo clappi*, however, it may usually be distinguished by the fact that the angle made by the ventral edge of the anterior area with the anterior edge of the anterior-median area is more

*Named from "Sir George Somers, Knight, Admirall of the Seas," who has been called the "Father of Bermuda." This name also was suggested by Dr. Mark.

obtuse. On the anterior area of *Teredo clappi* there are eighteen denticulate ridges to the millimeter, whereas in *Teredo somersi* there are usually only twelve. On the anterior-median area, the denticulate ridges are narrower in *Teredo somersi* than in *Teredo clappi* (*Teredo somersi* thirty-five, *Teredo clappi* twenty-eight to the millimeter), but the denticles on these ridges are considerably broader (*Teredo somersi* thirty-two, *Teredo clappi* forty to the millimeter).

The pallets of *Teredo somersi* are very different from those of *Teredo clappi*, the most important difference being that those of mature specimens show no trace of the sinus, or double cup, characteristic of *Teredo clappi*. Pallets of very young specimens, however, clearly show this sinus.

The entire length of the tube rarely exceeds fifty millimeters, and specimens less than fifteen millimeters in length frequently contain well developed embryos in the gills. The number of embryos in an individual is small; no specimen examined contained more than seventy-five, and small specimens had, in an apparently full litter, not more than twenty to twenty-five. Possibly because of this fact the species is rare and the damage caused by it practically negligible.

Specimens of this species have been found not only at Bermuda, but also in the test-blocks placed by the Committee on Marine Piling Investigations at the following locations: Channel 5 and two stations at Key West, Fla.; San Pedro de Macoris, Santo Domingo; Port au Prince, Haiti; and Christiansted, St. Croix, Virgin Islands.

In Bermuda, test-blocks placed at Agar's Island, Bar's Bay, Ireland Island, and St. George, all contained specimens of this species at irregular intervals. The first specimens found occurred in test-blocks placed in the water August, 1922, and removed January 15, 1923. No blocks removed before that date contained any specimens of this species.

Specimens from Florida and the West Indies are generally smaller than those from Bermuda; however, one specimen in wood from the Virgin Islands had a tube length of one hundred millimeters. Stenomorphic (Bartsch, 1923[b], p. 330) specimens are frequent in all localities.

Teredo (*Zopoteredo*) *johnsoni** Clapp. (Plate XII, Figs. 71-78.) Trans. Acad. Sci. of St. Louis, v. XXV.

Shell subglobular, white, covered with a thin, nearly transparent, colorless periostracum. The narrow incised line separating the anterior and the anterior-median areas very slightly curved. The ventral edge of the anterior area meeting the anterior edge of the anterior-median area in a nearly straight line, forming an angle of approximately 90°.

Externally, the anterior area large, with many evenly spaced denticulate ridges, which are of about the same width as the intervening spaces. There are sixteen of these ridges to the millimeter on the posterior-ventral portion of this area, each ridge bearing one hundred and twenty minute denticles to the millimeter (Plate XII, Fig. 71. The anterior-median area occupying, at its widest part, one-third of the entire median area. The denticulate ridges on this area, along a line continuous with the ventral edge of the anterior area, average thirty to the millimeter. There are twenty-six of these ridges in the type specimen, each ridge bearing approximately thirty-three denticles to the millimeter (Plate XII, Fig. 72). The middle-median area is narrow, divided longitudinally into nearly equal halves, the anterior half, with the continuation of the denticulate ridges, showing as narrow, diagonally descending growth lines, which curve upward, and become more or less obscure on the posterior half of the middle-median area. The posterior-median area large, occupying more than half of the entire median area, nearly smooth, showing only occasional, faint, incised growth lines. The auricle very small, being merely a continuation of the posterior-median area, with no trace externally of a separating groove or concavity.

Internally, a small, square hinge-plate in the left valve. The blade two-thirds of the length of the entire shell, thin, broad dorsally, the middle and

*Mr. Clapp says: "I take pleasure in naming this species for Mr. A. A. Johnson, Assistant to the Director of the Marine Piling Investigations Committee of the National Research Council."

ventral portions narrower, its entire length reflected slightly posteriorly. The ventral knob narrow, long, its base extending dorsally for a considerable distance. The juncture of the anterior with the anterior-median area marked by a narrow, thickened chord. The juncture of the auricle with the posterior-median area hardly visible.

Pallets (Plate XII, Fig. 73) with long, stout, opaque white stalks. The blade, short, broad, investing a considerable portion of the upper part of the stalk in a thin sheath. The outer face convex. The proximal third of the blade calcereous, arising from the stalk in an abrupt curve. The middle third swollen, covered with a light horn-colored periostracum. The distal third covered with a dark chestnut colored periostracum with a deep central sinus dividing this portion of the blade into two shallow cups, the outer face considerably more deeply indented than the inner. The inner face of the blade flat, its distal two-thirds covered with a periostracum irregularly streaked with narrow bands of light and dark chestnut.

The posterior end of the tube with a long delicate partition (Plate XII, Fig. 74) dividing the tube into equal parts.

The type (Mus. Comp. Zoöl. No. 45306) is from Guantanamo, Cuba.

The measurements of the type are:

Shell: Height 4.5 mm.; length 4.5 mm.

Pallets: Total length 4.3 mm.; length of stalk 3 mm.; width of blade 1.6 mm.

The shell of this species is very closely related to that of *Teredo clappi* Bartsch (Proc. Biol. Soc. Washington, 1923, 36, p. 96). However, the apophysis is shorter and narrower, the ventral knob smaller. The entire median area in *Teredo johnsoni* is always proportionately broader than in *Teredo clappi.* The range of variation of the denticulate ridges of both species is so great that no constant difference can be established, but the angle formed at the juncture of the ridges of the anterior area with those of the anterior-median area is always approximately 90° in *Teredo johnsoni*, whereas in *Teredo clappi* it is constantly obtuse, being rarely less than 100°.

The pallets are very different from those of any previously described species of *Zopoteredo* in that they are more nearly truly double cupped, being in this respect more like *Teredothyra.* In *Teredo somersi* the characteristic median sinus can be seen only in the pallets of the very young, never persisting in the mature specimens. In *Teredo clappi* it is frequently obscured or lost entirely in mature individuals, although always present in immature specimens. In *Teredo johnsoni* the sinus is constant in specimens of all ages.

Specimens of this species have been found in the test blocks placed by the Committee on Marine Piling Investigations at the following locations: Guantanamo, Cuba; Port au Prince, Haiti; Fajardo and San Juan, Porto Rico; St. Thomas, Virgin Islands.

This species is comparatively rare and the destruction caused by it very slight. Few specimens exceed 60 mm. in total length.

At Guantanamo, Cuba, a test block placed in the water on October 1, 1922, contained specimens 20 mm. in length on December 30. A special block made of shingles, placed in the water in April, 1923, contained several 60 mm. specimens July 7, 1923. At Port au Prince, Haiti, a test block submerged June 1 and removed August 14 contained *Teredo johnsoni* on January 2, 1923, and wood placed in the water July 1, 1923, contained small specimens on August 1, 1923. At Fajardo, Porto Rico, wood submerged from January 9 till April 30, 1923, contained several specimens of this species. At St. Thomas, Virgin Islands, wood submerged four months and removed January 1, 1923, contained several specimens.

Teredo (*Zopoteredo*) *fulleri** Clapp. (Plate XIII, Figs. 79-85) Trans. Acad. Sci. of St. Louis, v. XXV.

Shell subglobular, small, bluish white, covered with a strong, transparent periostracum. A thin, broadly curved, incised line separating the anterior

*Mr. Clapp says: "I have named this species for Mr. Nelson M. Fuller of the Massachusetts Institute of Technology, in recognition of the assistance he has given me in the study of the shipworm problem."

from the anterior-median area. The angle formed by the ventral ridges of the anterior area with the anterior rows of the anterior-median area, considerably more than 100°.

Externally, the anterior area, large. In height, slightly less than half that of the entire shell. The denticulate ridges of this area twice as wide as the spaces between them. There are in the vicinity of the ventral edge about twenty-five of these ridges to the millimeter, each ridge bearing one hundred and thirty minute denticles to the millimeter (Plate XIII, Fig. 79). In the type specimen, the anterior-median area at its widest part is one-half of the width of the entire median area and bears thirty-six closely crowded denticulate ridges averaging, in a line continuous with the ventral edge of the anterior area, forty teeth to the millimeter. Each ridge bears closely crowded, nearly square, denticles, there being forty-five of these denticles to the millimeter (Plate XIII, Fig. 80). The middle-median area is narrow, translucent, with the ventral ends of the ridges of the anterior-median area disappearing quickly or persisting only as faint growth lines. The posterior-median area opaque, milk white, smooth, except for microscopic incised growth lines. The auricle small, not clearly separated from the posterior-median area, the dorsal edge concave.

Internally, a large, sharp, curved hinge-plate in the left valve. The blade two-thirds of the length of the entire shell, thin, narrow, the ventral end broadly reflected posteriorly. The ventral knob small, somewhat narrower than the supporting middle-median area. The anterior-median area bearing a thickened chord in the vicinity of the anterior area. The auricle extending over the posterior-median area in a heavy callous, ending in an abrupt deep ridge, but with no trace of a shelf.

The pallet (Plate XIII, Fig. 81) with a very slender, delicate translucent stalk. The stalk can be seen to extend dorsally a considerable distance through the long, nearly opaque enveloping sheath of the blade. The blade long, narrow, with the sides nearly straight, opaque, milk white, covered with a very thin horn-colored periostracum, which is very difficult to see excepting at the extreme distal end. The outer face convex, the inner flat. The distal end slightly cupped, with the outer face of the blade divided for half its entire length by a narrow, deep sinus.

The type (Mus. Comp. Zoöl. No. 45307) is from Christiansted, St. Croix, Virgin Islands.

The measurements of the type are:

Shell: Height 3.5 mm.; length 3.5 mm.

Pallets: Total length 4 mm., equally divided between blade and stalk; width of blade 0.9 mm.

The shell of *Teredo fulleri* is very similar to that of other species of the subgenus *Zopoteredo*. It is perhaps most like that of *Teredo johnsoni*, from which it may be distinguished by the more obtuse angle formed by the anterior and anterior-median area, the shell being in this respect more nearly like that of *Teredo clappi*. The ridges of the anterior area are proportionately larger and the intervening spaces smaller. The internal ridge at the juncture of the anterior with the anterior-median area is constantly much more clearly marked in *Teredo fulleri* than in *Teredo johnsoni* or *Teredo clappi*. The shell is smaller, no specimens having been found exceeding 3.5 mm. in length or height.

The pallets differ greatly from those of any previously described species, so much so, that, were it not for the lack of any trace of a true internal shelf, I should not feel certain that the species belonged in the subgenus *Zopoteredo*. The most striking character of the pallet is the milk white color of the blade through almost its entire length. This is in marked contrast to the other species of *Zopoteredo*, in all of which a large portion of the blade of the pallet is covered with a dark colored periostracum. The long, narrow sinus being only on the external face of the blade, the distal end is not double cupped as in *Teredo johnsoni*.

This species is probably extremely rare, for it has been found in the numerous test boards placed by the Committee on Marine Piling Investiga-

tions throughout the West Indies only at Port au Prince, Haiti, and Christiansted, St. Croix, Virgin Islands. At the first named locality no specimen of this species occurred in test blocks, which were submerged from December 1, 1922, until June 1, 1923. These blocks were, however, well filled with several other species of shipworms. In a series of test blocks submerged June 1, 1923, one of which was removed and examined each month until October 1, all contained numerous specimens of several species of shipworms, but only the block which had been submerged two months, having been removed August 1, contained specimens of *Teredo fulleri*. Of seventy-five shipworms found in this block only five belonged to this species, the largest with a tube 30 mm. long.

At Christiansted, test blocks submerged September 15, 1922, and removed bi-monthly, contained many shipworms belonging to several species. No *Teredo fulleri* were found in these blocks until September 1, 1923. The blocks removed from the water on that date contained one 20 mm. specimen. The block removed on September 15, 1923, contained twenty specimens of *Teredo fulleri*, the largest with a tube 40 mm. in length.

Two other undescribed species have not been placed in sub-genera and will require further study. They are species *F* Clapp and *Z* Clapp.

Species *F*, which is destructive, has been found at:

Guantanamo, Cuba.
Fajardo, Porto Rico.
San Pedro de Macoris, San Domingo.
St. Thomas, Virgin Islands.
Coco Solo, Canal Zone.

Species *Z* appears to be of little economic importance and has been found only at Coco Solo, Canal Zone.

Bankia

This genus has a world-wide distribution, and its species are generally of large size. Most if not all species are thought to fertilize the eggs in the water, and consequently an examination of specimens does not give as good criteria for judging the capacity for destruction of the different species as is the case for most species of the genus *Teredo*.

Bankia (*Bankia*) *setacea* Tryon, Proc. Acad. Nat. Sci., Philadelphia, ser. 2, v. 7, 1863; pp. 144-145; pl. 1, figs. 2, 3.

This is a very rapidly growing species which sometimes is reported to reach a length of four feet. It will frequently destroy a pile in one season, and has a very wide distribution on the Pacific Coast. (Fig. 16.) It is one of the most destructive of the American shipworms. Specimens have been received from the following harbors:

San Diego, Cal.
Los Angeles, Cal.
San Francisco, Cal.
Coos Bay, Ore.
Puget Sound, Wash.
Ketchikan, Alaska.
Petersburg, Alaska.
Juneau, Alaska.
Seward, Alaska.
Kodiak, Alaska.

Bankia (*Bankiella*) *gouldi* Bartsch. U. S. Nat'l Mus. Bull. 122, pp. 1-12, pl. 2, 3 and 8, fig. 3; pl. 9-16; pl. 30, fig. 4.

While this species is not reported to reach so great a size as *Bankia setacea*, it is exceedingly destructive in practically all the locations where found. It had been generally supposed to require a high salinity, but its presence at Great Bridge, Va., and in the Mobile River shows that it has a previously unsuspected ability to live in water of low salinity, and the experiments of the Chemical Warfare Service (page 193) tend to confirm this supposition.

Specimens have been found, generally in large numbers, in the following harbors:

Newport News, Va.	Sabine Pass, Tex.
Norfolk, Va.	Galveston Bay, Tex.
Great Bridge, Va.	Lower Houston Channel, Tex.
Beaufort, N. C.	Rockport, Tex.
Charleston, S. C.	Aransas Pass, Tex.
Savannah, Ga.	Corpus Christi, Tex.
Brunswick, Ga.	Pt. Isabel, Tex.
Fernandina, Fla.	Gulfport, Miss.
Tampa Bay, Fla.	Pascagoula, Miss.
Pensacola, Fla.	Port Eads, La.
Mobile, Ala.	

Bankia (*Bankiella*) *mexicana* Bartsch. U. S. Nat'l Mus. Bull. 122, 1922, p. 10, pl. 8, fig. 1; pl. 30, fig. 2.

This species, found in test blocks from Mazatlan and Topolobampo, Mexico, resembles *Bankia setacea* in size and destructiveness.

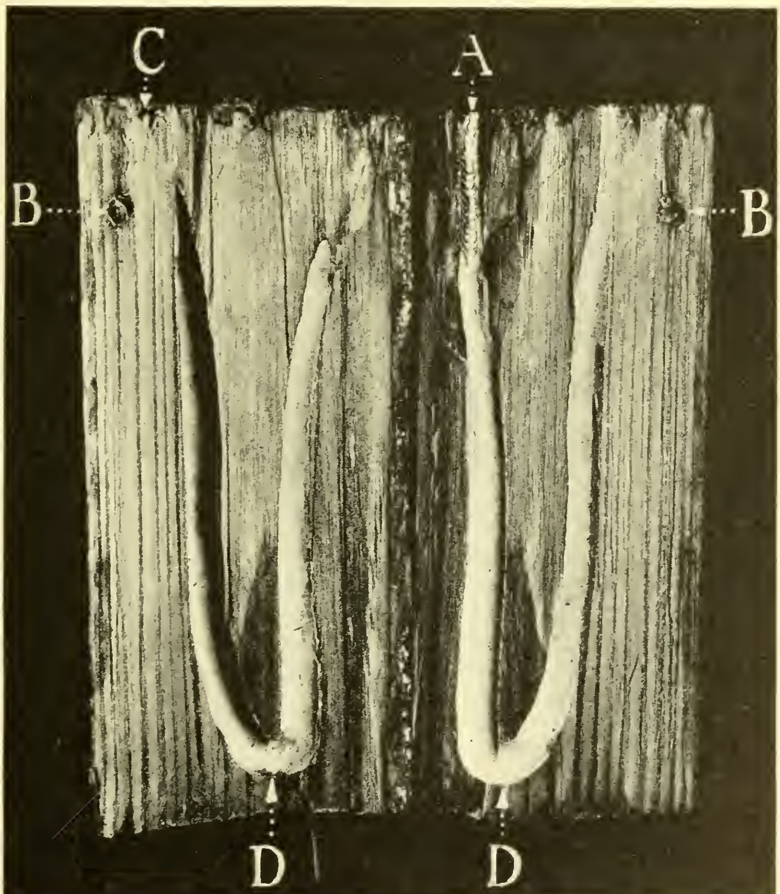


FIG. 16—*Bankia setacea* 12 INCHES LONG IN TEST BLOCK FROM COOS BAY, ORE. BLOCK PLACED JUNE, 1921; REMOVED OCTOBER, 1922.

Bankia (*Neobankia*) *zeteki* Bartsch. U. S. Nat'l Mus. Bull. 122, 1922, p. 9; pl. 6, 7 and 30, fig. 1.

This species, found in test blocks only at Coco Solo, Canal Zone, is a destructive species of apparently limited range.

Several undescribed species of *Bankia* have been identified and will later be described. For convenience, as in the case of the genus *Teredo*, they are referred to by letter in the following tables showing their distribution:

Bankia (*Bankia*) *sp. I* Clapp.

Jupiter Inlet, Fla.
Miami, Fla.
St. Petersburg, Fla.
Tampa, Fla.
Pensacola, Fla.

Bankia (*Bankia*) *sp. K* Clapp.

Fajardo, Porto Rico.
San Juan, Porto Rico.

Bankia (*Bankia*) *sp. T* Clapp.

Guantanamo, Cuba.
San Juan, Porto Rico.
Mayaguez, Porto Rico.
Port au Prince, Haiti.
San Pedro de Macoris, San Domingo.
San Domingo, San Domingo.
Coco Solo, Canal Zone.
St. Thomas, Virgin Islands.

Bankia (*Bankiella*) *sp. X* Clapp.

Mayaguez, Porto Rico.
Port au Prince, Haiti.
Coco Solo, Canal Zone.

Bankia sp. C Clapp.

Jupiter Inlet, Fla.
Pensacola, Fla.
Gulfport, Miss.

Martesia

Comparatively little is known regarding this genus of wood borers, and since there is so much confusion regarding specific identification it has been thought advisable to show the distribution of the entire genus rather than to attempt to divide it into species.

The rate of destruction by *Martesia* is not so rapid as that by some of the shipworms under favorable conditions, though from pile specimens received from Snead's Island, Tampa Bay and from test blocks from Cavite, Philippine Islands, it appears possible that in these locations a pile might be destroyed in less than two years.

Martesia seems to be less affected by creosote than other molluscan borers, as is shown by its having sunk a barge built of heavily creosoted lumber (24 pounds, per cubic foot) in a few months. Wood sheathing with a layer of tarred felt under it has also been penetrated by these animals, and it seems probable that the only sure protection against them is metal sheathing or concrete or metal casing.

Martesia has been found in the following harbors:

Charleston, S. C.
St. Petersburg, Fla.
Snead's Island, Fla.
Tampa, Fla.
Cedar Key, Fla.
Pensacola, Fla.
Ft. Morgan, Mobile Bay, Ala.
Pascagoula, Miss.
Galveston, Tex.
Guantanamo, Cuba.
San Juan, Porto Rico.
Mayaguez, Porto Rico.
Coco Solo, Canal Zone.
Mazatlan, Mexico.
Pearl Harbor, Territory of Hawaii.
Nawiliwili, Territory of Hawaii.
Cavite, Philippine Islands.

Martesia striata Linn.* (Plate XIV, Figs. 86-90).

This species has occurred occasionally in the blocks from Pearl Harbor, rarely more than three or four small specimens, of a maximum length of 2 cm., occurring in any one block. That it is of economic importance in this locality has been shown in an earlier paper (Kofoid and Miller, 1923), where instances were cited and figured of damage to piling, and of penetration through redwood sheathing and an inside layer of tarred ship's felt.

Burrows attributed to this species were also found in one of the blocks from Nawiliwili, although the animals themselves had been lost out before the block was sent in, thus precluding certain identification.

At Cavite attack by this species on the test blocks has been rapid and extremely destructive, the damage by *Teredo* at this locality, although considerable, being secondary to that occasioned by *Martesia*. Blocks exposed four months or longer were usually in a crumbling condition, the surface being riddled by small *Martesia*, mostly less than 2 cm. in length. The deeper portions of the block were at the same time penetrated by the longer burrows of *Teredo*.*

*Wood Boring Mollusks from the Hawaiian, Samoan and Philippine Islands, (Univ. Calif. Publ. Zool., V. 26, No. 7).

EXPLANATION OF PLATES*

PLATE I

Chelura insulae, and *Limnoria andrewsi*

FIG. 1. *Chelura insulae,* male, from Tutuila, Samoa. x 17.

2. *Chelura insulae,* female, from Tutuila, Samoa. x 17.

3, 4 and 5. *Limnoria andrewsi* from Tutuila, Samoa. Dorsal, lateral and ventral views of female carrying advanced embryos in brood pouch. x 17.

(By permission of Univ. Cal. Publ. Zool.)

PLATE II

FIG. 6. Portion of a 3½″ x 3½″ x 6″ test block submerged 8 months at Tutuila, showing damage done by *Limnoria andrewsi* and *Chelura insulae.* The ends of a few *Teredo* burrows have been exposed. x ¾.

7. All that remained of a 2″ x 3½″ x 5″ test block submerged 8 months in Honolulu Harbor. The major damage was occasioned by *Limnoria andrewsi; Limnoria lignorum* and *Chelura insulae* were also present in the block. All *Teredo* were dead as a result of exposure of their burrows by the crustacean borers. x ¾.

8. Portion of block from Tutuila, showing specimens of *Chelura insulae* in place in burrows. One *Limnoria andrewsi* is seen in place near lower left corner. x 5.

(By permission of Univ. Cal. Publ. Zool.)

PLATE III

FIG. 9. *Teredo parksi* from Pearl Harbor, exterior of right valve. x 7.

10. Same, interior of right valve.
11. Same, outer face of pallet.
12. Same, inner face of pallet.
13. Shells of *Teredo parksi* from Cavite. x 5.
14. Pallets of *Teredo parksi* from Cavite. x 5.
15. Shells of *Teredo parksi* from Honolulu Harbor. x 5.
16. Pallets of *Teredo parksi* from Honolulu Harbor. x 5.
17. Shells of *Teredo parksi* from Tutuila. x 5.
18. Pallets of *Teredo parksi* from Tutuila. x 5.

(By permission of Univ. Cal. Publ. Zool.)

---

*Acknowledgment of the thanks of the committee is here made to the Academy of Arts and Sciences, Boston, Mass.; the Academy of Science of St. Louis, Mo.; and the University of California Publications in Zoology for permission to use the engravings as indicated.

Plate IV

Teredo furcillatus Miller
Teredo samoaensis Miller

Fig. 19. *Teredo furcillatus* from Tutuila, exterior of right valve of the type. x 10.
20. Same, interior of right valve.
21. Same, outer face of pallet.
22. Same, inner face of pallet.
23. Series of pallets of *Teredo furcillatus* from Tutuila, selected to show variations. x 7.
24. *Teredo samoaensis* from Tutuila, exterior of right valve of the type. x 10.
25. Same, interior of right valve.
26. Same, outer face of pallet.
27. Same, inner face of pallet.
28. Series of pallets of *Teredo samoaensis* from Tutuila, selected to show variations. x 7.

(By permission of Univ. Cal. Publ. Zool.)

Plate V

Teredo affinis Deshayes
Teredo trulliformis Miller

Fig. 29. *Teredo affinis* from Nawiliwili, exterior of right valve. x 10.
30. Same, interior of right valve.
31. Same, outer face of pallet.
32. Same, inner face of pallet.
33. Series of pallets of *Teredo affinis* from Nawiliwili, selected to show variations. x 10.
34. *Teredo trulliformis* from Honolulu Harbor, exterior of right valve of the type. x 10.
35. Same, interior of right valve.
36. Same, outer face of pallet.
37. Same, inner face of pallet.

(By permission of Univ. Cal. Publ. Zool.)

Plate VI

Teredo bartschi Clapp

Fig. 38. Pallets of *Teredo bartschi*, dry, showing distorted chitinous portion. x 10.
39. Pallets showing normal condition of the chitinous portion. Type, Mus. Comp. Zool., No. 45301. x 12.
40. Pallets showing position in relation to the internal lamellae of the tube. x 10.
41. Destruction caused by *Teredo bartschi* in test block submerged eight weeks. Natural size.

Plate VII

Teredo bartschi Clapp

Fig. 42. Exterior of right valve. Type, Mus. Comp. Zool., No. 45301. x 12.
43. Exterior of left valve. Type. x 12.
44. Interior of left valve. Type. x 12.
45. Interior of right valve. Type. x 12.
46. Dental ridges of the anterior portion. x 200.
47. Dental ridges of the median portion. x 200.

Plate VIII

(All figures reduced 5/16)

Teredo portoricensis Clapp

Fig. 48. Denticulate ridges of the anterior portion. x 100.
49. Denticulate ridges of the anterior-median portion. x 100.
50. Pallets. x 14.
51. Exterior of right valve. x 14.
52. Exterior of left valve. x 14.
53. Interior of left valve. x 14.
54. Interior of right valve. x 14.

(By permission of Academy of Science of St. Louis.)

Plate IX

Teredo batilliformis Clapp

Fig. 55. Exterior of right valve. x 14.
56. Exterior of left valve. x 14.
57. Interior of left valve. x 14.
58. Interior of right valve. x 14.
59. Pallet, outer face. x 14.
60. Pallet, inner face. x 14.

(By permission of Amer. Acad. Arts and Sci.)

Plate X

Teredo somersi Clapp

Fig. 61. Exterior of right valve. x 14.
62. Exterior of left valve. x 14.
63. Interior of left valve. x 14.
64. Interior of right valve. x 14.
65. Pallet, outer face. x 14.
66. Pallet, inner face. x 14.

(By permission of Amer. Acad. Arts and Sci.)

Plate XI

Fig. 67. *Teredo batilliformis*, denticulate ridges, anterior area. x 130.
68. *Teredo batilliformis*, denticulate ridges, anterior-median area. x 130
69. *Teredo somersi*, denticulate ridges, anterior area. x 130.
70. *Teredo somersi*, denticulate ridges, anterior-median area. x 130.

(By permission of Amer. Acad. Arts and Sci.)

Plate XII

(All figures reduced 3/7)

Teredo johnsoni Clapp

Fig. 71. Denticulate ridges of the anterior portion. x 130.
72. Denticulate ridges of the anterior-median portion. x 130.
73. Pallets. x 13.
74. Posterior portion of the tube. x 13.
75. Exterior of right valve. x 13.
76. Exterior of left valve. x 13.
77. Interior of left valve. x 13.
78. Interior of right valve. x 13.

(By permission of Academy of Science of St. Louis.)

Plate XIII

(All figures reduced 3/7)

Teredo fulleri Clapp

Fig. 79. Denticulate ridges of the anterior portion. x 125.

80. Denticulate ridges of the anterior-median portion. x 125.
81. Pallets. x 12.
82. Exterior of right valve. x 17.
83. Exterior of left valve. x 17.
84. Interior of left valve. x 17.
85. Interior of right valve. x 17.

(By permission of Academy of Science of St. Louis.)

Plate XIV

Fig. 86. *Martesia striata* from Pearl Harbor, dorsal view. x 2.

87. Same, lateral view.
88. Same, ventral view.
89. Split section of a test block submerged 5 months at Cavite, showing *Martesia striata* in place in burrows. The burrows exhibiting a calcareous lining are those of Teredo. x 9/10.
90. Portion of the surface of a block submerged 9 months at Cavite, showing destruction by *Martesia striata*. x 9/10.

(By permission of Univ. Cal. Publ. Zool.)

FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

CHELURA INSULAE AND LIMNORIA ANDREWSI

FOR EXPLANATION OF PLATE SEE PAGE 53

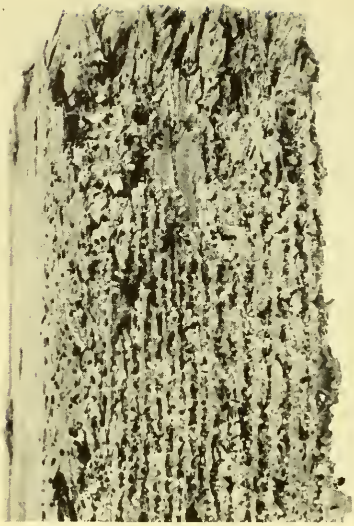


FIG. 6

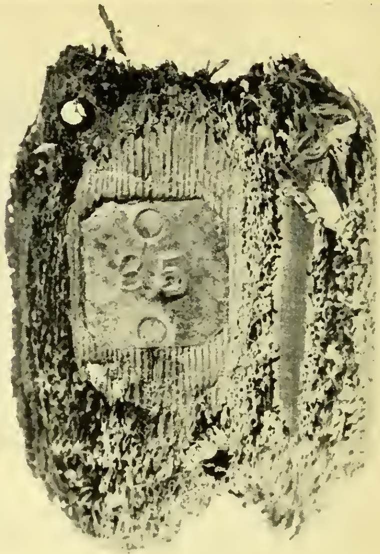


FIG. 7

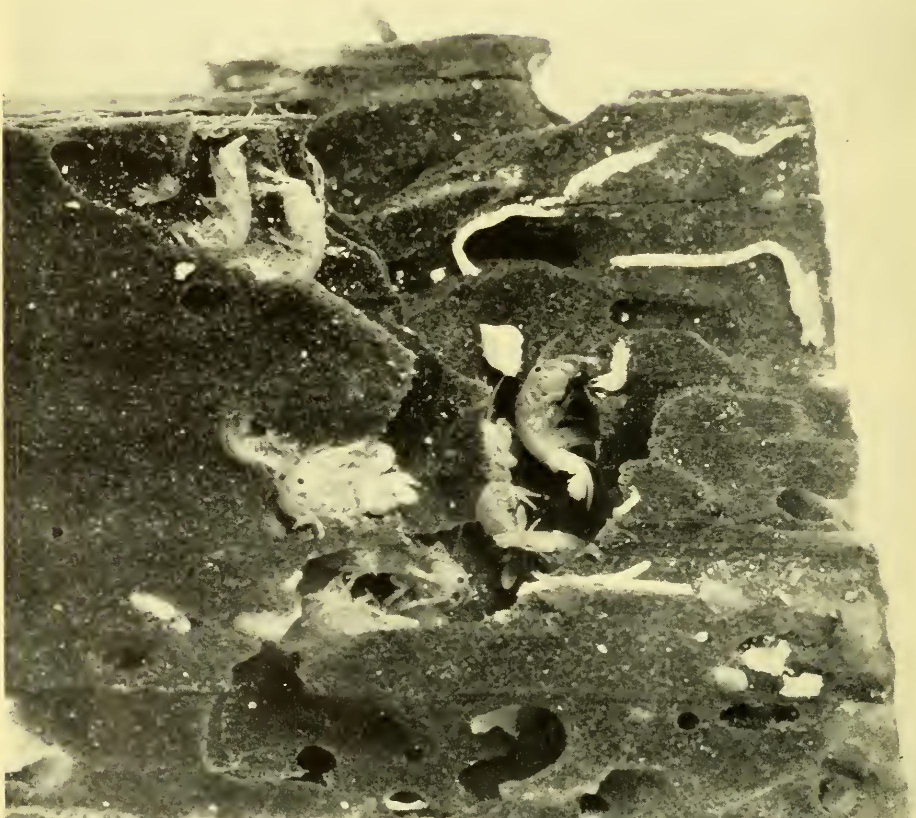


FIG. 8

TYPICAL WORKINGS OF LIMNORIA AND CHELURA

FOR EXPLANATION OF PLATE SEE PAGE 53

FIG. 9

FIG. 10

FIG. 11

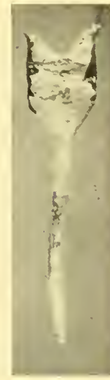


FIG. 12

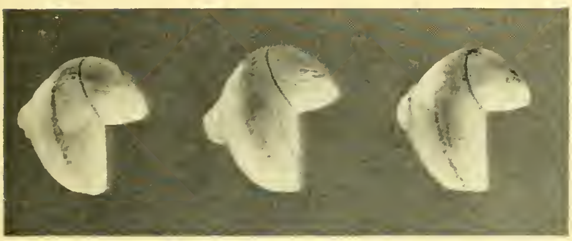


FIG. 13

FIG. 14

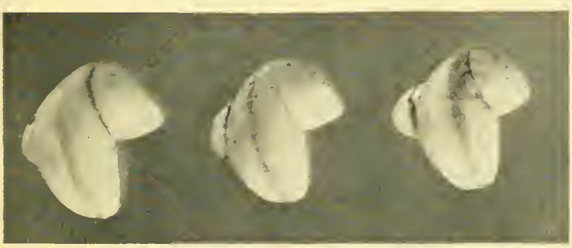


FIG. 15

FIG. 16

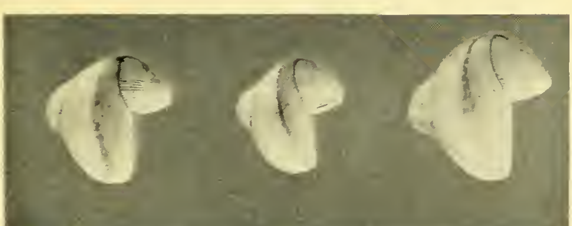


FIG. 17

FIG. 18

TEREDO PARKSI

FOR EXPLANATION OF PLATE SEE PAGE 53

FIG. 19

FIG. 20

FIG. 21

FIG. 22

FIG. 23

FIG. 24

FIG. 25

FIG. 26

FIG. 27

FIG. 28

TEREDO FURCILLATUS AND TEREDO SAMOAENSIS

FOR EXPLANATION OF PLATE SEE PAGE 54

FIG. 29

FIG. 30

FIG. 31

FIG. 32

FIG. 33

FIG 34

FIG. 35

FIG. 36

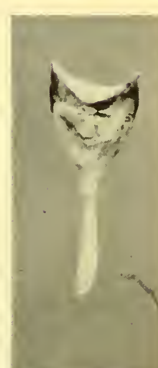


FIG. 37

TEREDO AFFINIS AND TEREDO TRULLIFORMIS

FOR EXPLANATION OF PLATE SEE PAGE 54

FIG. 38

FIG. 39

FIG. 40

FIG. 41

TEREDO BARTSCHI

FOR EXPLANATION OF PLATE SEE PAGE 54

FIG. 42

FIG. 43

FIG. 44

FIG. 45

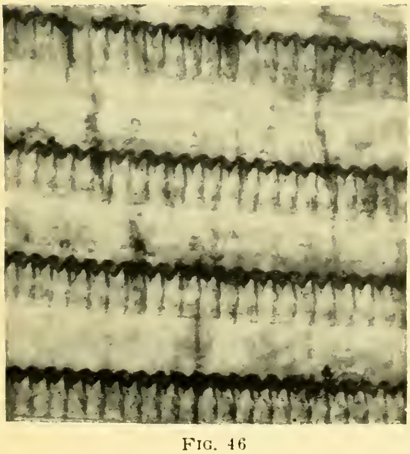


FIG. 46

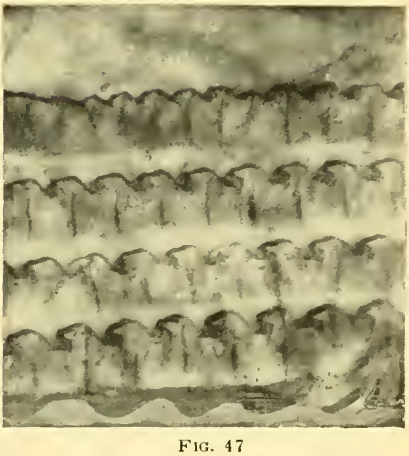


FIG. 47

TEREDO BARTSCHI

FOR EXPLANATION OF PLATE SEE PAGE 54

Fig. 48

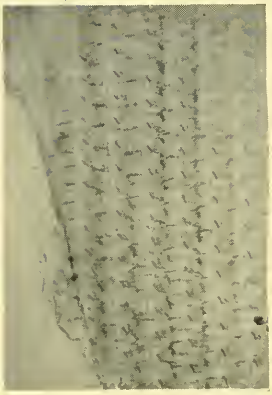


Fig. 49

Fig. 50

Fig. 51

Fig. 52

Fig. 53

Fig. 54

Teredo portoricensis

FOR EXPLANATION OF PLATE SEE PAGE 55

FIG. 55

FIG. 56

FIG. 57

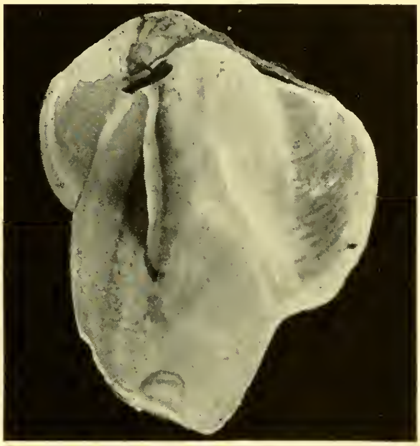


FIG. 58

FIG. 59

FIG. 60

TEREDO BATILLIFORMIS

FOR EXPLANATION OF PLATE SEE PAGE 55

FIG. 61

FIG. 62

FIG. 63

FIG. 64

FIG. 65

FIG. 66

TEREDO SOMERSI

FOR EXPLANATION OF PLATE SEE PAGE 55

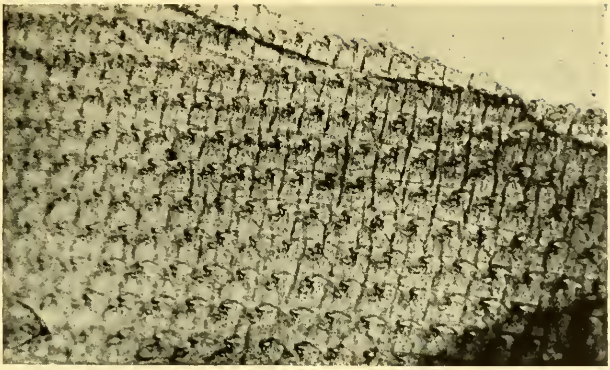


FIG. 67

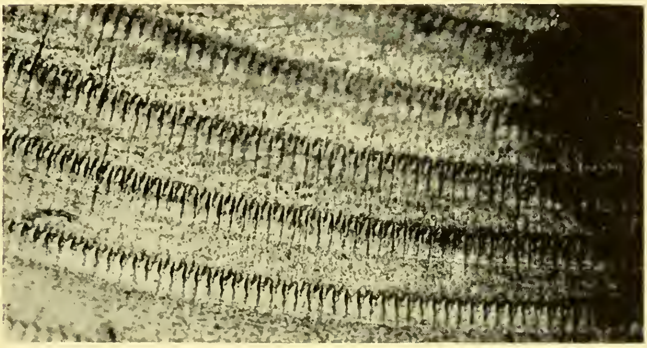


FIG. 68

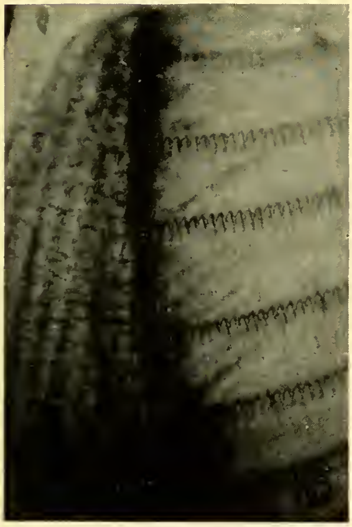


FIG. 69

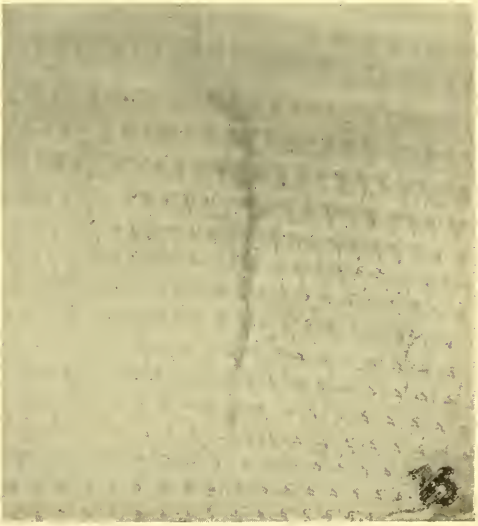


FIG. 70

TEREDO BATILLIFORMIS AND TEREDO SOMERSI

FOR EXPLANATION OF PLATE SEE PAGE 55

FIG. 71

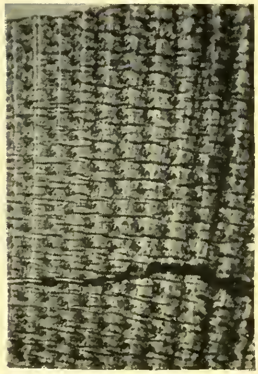


FIG. 72

FIG. 73

FIG. 74

FIG. 75

FIG. 76

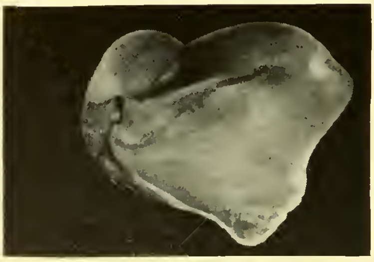


FIG. 77

FIG. 78

TEREDO JOHNSONI

FOR EXPLANATION OF PLATE SEE PAGE 55

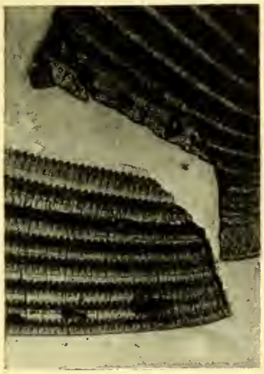


FIG. 79

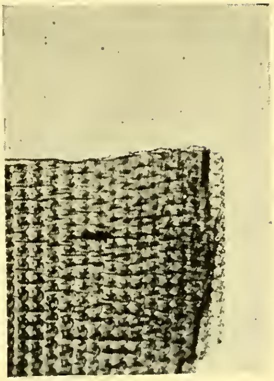


FIG. 80

FIG. 81

FIG. 82

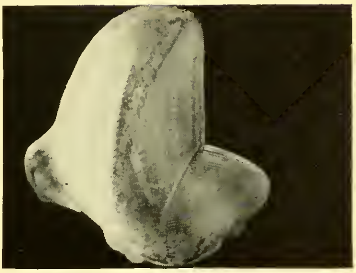


FIG. 83

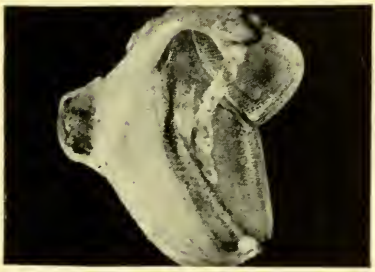


FIG. 84

FIG. 85

TEREDO FULLERI

FOR EXPLANATION OF PLATE SEE PAGE 56

FIG. 86

FIG. 87

FIG. 88

FIG. 89

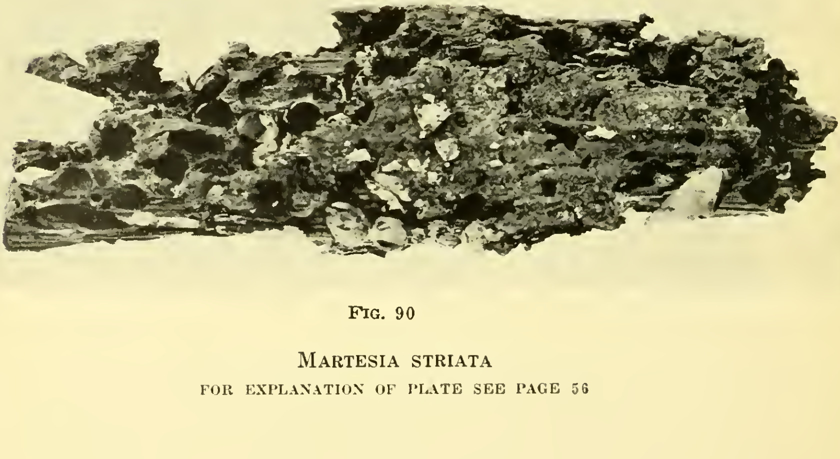


FIG. 90

MARTESIA STRIATA

FOR EXPLANATION OF PLATE SEE PAGE 56

CHAPTER IV

ANIMALS BORING IN ROCK

Crustacea

Some species of *Sphaeroma* are found in mud and soft rock, but so far as is indicated by records reaching the Committee they have not damaged masonry structures.

Mollusca

There are several genera and a large number of species of rock boring mollusks found in all parts of the world.

There has been much discussion as to whether these animals did their boring by mechanical or chemical means, or a combination of the two. It was at first thought to be impossible for so fragile a structure as the shell of one of these animals to penetrate hard rock, and that consequently the action must be chemical. The method of boring used by the family Pholadidae was described by a Dutch merchant, Leendert Bomme, in 1778, (W. Vrolik, Comptes Rendus, 1853, 36:797) as purely mechanical without the aid of any acid. This was further demonstrated about 1840 by finding these animals boring in mica schist which could not have been dissolved by acid.

Some species of rock borers working in limestone, such as the sponges and polycheate worms, in addition to some species of mollusks, do undoubtedly use chemical means of boring.

While rock borers are very widely distributed, no reports have reached the Committee of the destruction of stone masonry harbor structures by rock borers, but the breakwater at Plymouth, England, is reported to have been damaged by them. There is a possibility of the destruction of masonry when the stone is soft and the borers active. (Fig. 17.)

Only two authentic reports have reached the Committee of attack on concrete structures, but in both cases serious damage occurred.

The La Boca dock in the Panama Canal Zone was built by the French Company in 1898 on cylinder piers 5 meters in diameter, incased in a metal cofferdam which was left in place. There is no record of the materials or method of construction, but there are several concrete structures on shore in the vicinity which were built at the same time and supposedly with the same materials. These structures are in excellent condition. The metal cofferdam corroded and through the holes thus formed the borers attacked the concrete. In 1922 the damage was so great that the dock was condemned. It is very probable that the chemical disintegration of the concrete was much accelerated by the work of the borers, and, conversely, that the destructive work of the borers was assisted by the softening of the concrete by chemical action.

The animal responsible for most of this damage was the *Lithophaga aristata* Dillwyn, but Mr. Zetek, specialist in tropical entomology, on the staff of the Canal organization, reports a number of other rock borers in the Canal Zone in part as follows:

> "The Pholadidae are not the only rock-boring mollusks we have. They are the principal and most destructive ones.

"We have *Carditamera affinis* Brod. (family Carditidae), which also bores into rock along the shore, and also members of the genus *Saxicava* (family Saxicavidae) are found in rocks. I am not positive of the species of *Saxicava* that we have here, but I feel reasonably certain both *purpurascens* Sby. and *solida* Sby. are present in our fauna.

"In the Pholas-type of boring mollusk, the work is done by means of a filing or rasping action of the shell, which has a row of hard spines or ridges near the front edge. They usually avoid very hard rocks. There is no solution-process involved; it is all mechanical rasping, and those that are in the harder kinds of rocks have their 'drilling' parts quite dull when old, whereas those in the softer rocks, maintain them quite slender and sharp.

"In the preceding paragraph I omitted the genus *Petricola*, of which we have represented in our fauna the species *denticulata* Sby. and *robusta* Sby. They are rock-borers. There is very little data available on the actual destructiveness of many of these species. The Petricolas belong to the family of Petricolidae.

"In *Lithophaga* (syn. *Lithodomus*) there is no structure present with which the mollusk could scrape or bore. Instead, there is a special gland, present only in those species that bore into rocks, which secretes a substance which has a solvent action on the rock material, at any rate, that is the presumption and it appears to be true. The solution turns litmus pink.

"Such species, which secrete a rock-solvent, are, of necessity, protected by a thick covering (periostracum), as otherwise the solvent would also attack the shell-covering of the animal. The *Pholas* type has no such a covering. In *Saxicava* there is a periostracum but it is much eroded and could not protect the shell if there was any rock-solvent secreted.

"It is remarkable that a mollusk, when very young, should purposely take refuge in a small crevice or cavity, and make this its voluntary prison for life, that it should enlarge its cell as growth made demands for more space, and yet, to be unable even, in many cases, to turn about in its snugly fitting home.

"As to the sponges and worms that burrow into rocks, I have very little data on our local species that have these habits. We have a sponge, a *Cliona*, which usually attacks oyster shells. Sollas quotes Topsent (Arch. Zool. Exp. (3) viii p. 36, to the effect that as borers into oyster shells, the Clionidae may be reckoned as being of practical importance, and in some cases they even devastate the rocks, penetrating to a depth of some feet and causing them to crumble away."

The other case of damage to concrete occurred at Los Angeles, Cal., and is described in the 3rd Annual Progress Report of the San Francisco Committee, 1923, as follows:

"In the work of widening the channel in Los Angeles Harbor, about November 13, 1922, it became necessary to remove some old wooden piling which had been jacketed some years previously with concrete. In looking over these piles, Mr. Hughes observed that some of the jackets had been attacked by borers, and investigated further. Of 18 jackets examined at this location, known as the old Fish Cannery Wharf, across the channel from the foot of 5th Street, San Pedro (see map of Los Angeles Harbor), 16 were found to be more or less attacked; about 5 were considered to be badly attacked (6 borers or more per square foot of exposed surface); the others contained fewer, and some only an occasional borer. The two jackets which did not contain borers stood in shallower water than the others.

"The exact date at which these piles were driven could not be determined, but it was probably several years prior to 1909, at which time it became necessary to jacket them with concrete to protect them from *Limnoria* or other wood borers. The jackets had accordingly been in place 14 years. The length of time during which they were actually exposed to attack by the rock borers, however, is probably considerably less than this, as the form lumber was left in place outside the jackets, and would deter the pholad borers from entering the concrete until the encasing wood was destroyed by wood borers.

FIG. 17—SPECIMENS OF STONE FROM RIP-RAP AROUND WEST RIGOLETS LIGHTHOUSE, LA., PERFORATED BY BORERS — *Lithophaga (Dulerus) Bisculata* ORBIGNY AND *Gastrochaena Ovata* SOWERBY

"One of these piles was available for examination a month later by the junior author (Dr. R. C. Miller) of this report. The jacket was above seven feet long, having extended from mud line up to about mean low water. It consisted of cement mortar with no coarse aggregate (see screen test below), averaging 2½ inches in thickness, and sufficiently hard that some difficulty was experienced in breaking it up with a 15-pound iron bar to secure samples.

"The outside form lumber was still partly in place. It had originally consisted of 1-inch redwood, as seen at one place where it had been protected by a cleat. Elsewhere it had been badly attacked by *Limnoria* and *Teredo diegensis*, so that only a thin shell of it remained adhering to the concrete. This thin layer of wood, however, still covered all of the jacket except about one foot at the top, and one corner, where the form had sprung apart, leaving a gap through which the rock borers could enter. In this area nearly 40 of the borers occurred, averaging 7 or 8 to the square foot.

"The mollusks were in general a little larger than a man's thumb. The largest one found occupied a burrow measuring 1⅜ inches in diameter at its widest portion. Two borers in this jacket had penetrated the concrete until they came in contact with the wood within, but none had actually bored into the wood. One indeed had turned and continued boring in the concrete parallel to the surface of the wood, to avoid entering the latter.

"Mr. Hughes reported that, of the jackets examined by him, one other was attacked more heavily than this in proportion to the surface exposed; but it consisted of a very poor concrete, badly disintegrated.

"The discovery of the borers in concrete at this locality led to examination of other concrete jacketed piles in the harbor.

"Mr. Ludlow stated that, of 12 pile jackets examined by him at the old Blinn Lumber Company Wharf, opposite Berth 229 in Los Angeles Harbor, 3 were rather badly attacked by borers. Mr. Sadler reported that he had broken open 12 concrete jackets at the First Street Ferry landing, of which 3 were found to be attacked, one quite badly, the others containing from 3 to 6 borers each. Of 75 such jackets examined by Mr. Sadler at the Kerckhoff-Cuzner Wharf, about 50 per cent were found to contain borers, and about 20 per cent were quite badly attacked.

"Dr. Miller had the privilege of going over this ground again with Messrs. Hughes, Ludlow and Sadler on December 16. A number of other jackets were broken open, and a considerable quantity of specimens secured.

"The species occasioning most of the damage was found to be *Pholadidea penita* Conrad, known commonly as the "rock clam." (Fig. 18.) It occurred from two feet above mean low water to one foot below, which was the lowest level at which we were able to work. It doubtless similarly occurs on down to the mud, even in deep water, as it has been dredged in San Francisco Bay at a depth of fifty fathoms.

"This borer, unlike *Teredo*, has the body entirely enclosed within the two valves of the shell, which are ovate, tapering somewhat posteriorly and ending in leathery flaps. During the period of active boring life, the foot protrudes through a rather large anterior gape between the valves; but after cessation of boring, and perhaps in the interim between periods of boring activity, this gape is closed over by a calcareous plate, giving the borer the appearance seen in the photographs. It will be noted that the anterior portion of the shell is ribbed and somewhat denticulated, either for rasping purposes, or to grip the sides of the burrow.

"This species is edible, and is used for food in localities where it occurs in sufficient abundance to make worth while the labor of removing it from its rocky domicile, which is usually done by means of iron bars.

"Another boring species found in concrete pile jackets examined by us here was *Platyodon cancellata* Conrad, a near relative of the soft-shelled clam (*Mya arenaria*). This borer normally inhabits stiff mud and clay. It was found in the pile jackets only sparsely, and only in decidedly poor concrete.

"A third species occurring in the concrete jackets was the so-called 'nestler,' *Petricola carditoides* Conrad, which is believed not to bore on its own account, but to inhabit natural cavities or holes bored by other organisms.

"As regards extent of the damage occasioned by borers in concrete, a review of the data assembled by Mr. Hughes, Mr. Ludlow, Mr. Sadler and Dr. Miller, indicates that, of concrete jacketed piles at four different locations in Los Angeles Harbor, in fact at every point in the inner harbor where such piles exist, about 50 per cent have been more or less attacked, of which rather more than one-fifth have been very considerably bored. Of those not attacked, a number stood so well inshore as to be but little exposed to the action of the borers. If all such piles were eliminated from the count, the percentage of jackets damaged would be considerably higher.

"These jackets were in general of cement mortar poured around the piles by setting forms after the piles were driven. Some of the jackets had given service in sea water over a period of fourteen years. The hardness of the mortar was such that a sample of the best mortar in which the borers were found could be readily cut with the thumb nail.

"Mr. A. A. M. Russell, Testing Engineer, made a crushing test of the best sample submitted, finding the crushing strength of a specimen $2\frac{1}{2}'' \times 3\frac{1}{2}'' \times 4\frac{1}{2}''$ high to be 1726 pounds per square inch. This sample when crushed showed an encased sand pocket from which the aggregate could be readily picked with the fingers. Mr. Russell reports the grading of the aggregate, as follows:

Screen	Percentages
10-20	1.78
20-30	.89
30-50	4.46
50-80	51.78
80-100	16.07
100-200	16.07
Pass 200	8.94

Fig. 18—Pholads in Concrete Casings at Los Angeles, Cal.

"Approximately 93 per cent of the total aggregate passed the 50 mesh screen.

"It has commonly occurred in jacketing piles in place, that the concrete has been 'drowned' either by the presence of too much water in the mix or by depositing the material in the water, causing segregation and laitance and rendering such structures especially susceptible to borer action. Whether or not concrete of greater hardness, containing approximately 90 per cent of assorted aggregate in excess of the 50 mesh screen as contrasted with mortar having only 7% above 50 mesh, remains for further investigation. An inspection of concrete jacketed piles at Pier 34 and at Fisherman's Wharf at San Francisco failed to disclose borers. The type of piles selected was similar in construction to the Los Angeles type in that they were jacketed in the water, but the aggregate consisted of rock and sand and produced a fairly sound concrete. It is possible that these piles have not been exposed to attack on account of the mud shores of San Francisco Bay. However, the piles at Fisherman's Wharf are located at the inner end of the Golden Gate within one-half mile of Fort Mason, at which location rock borers have been reported in shale rocks."

These two instances show the possibility of serious damage to concrete structures by both types of boring mollusks, but the known wide distribution of these animals and the fact that only these two instances of damaged structures have been reported would seem to indicate that the danger, while existing, does not appear to be very great. Careful inspections should be made of concrete structures where these rock borers are known to exist, and further biological study should be made of them.

CHAPTER V

TIMBER FOR WHICH IMMUNITY IS CLAIMED

Statements frequently appear that certain tropical and other woods are immune from attack by marine borers. All available information on this subject has been studied to see whether any of these claims could be considered as proven to a sufficient degree to justify the importation of timber.

In 1913, Mr. A. K. Armstrong at the Forest Products Laboratory, Department of Agriculture, prepared a tabulation of all service records and records of tests which could be obtained as to the resistance of unprotected timber to the attack of marine borers. This report, the reports of the Institution of Civil Engineers "Deterioration of Structures in Sea-Water," of 1920, 1921 and 1922, as well as records obtained from other reliable sources, furnish the basis for the information following. The Forest Products Laboratory report contains 771 items of which 312 refer to timbers of the temperate zone generally recognized as not being resistant to borer attack, while the remainder are principally tropical or sub-tropical timbers.

There is great difficulty in the study of tropical timbers on account of the different local names given to these timbers, and therefore it has been necessary to eliminate from consideration some of those of which the botanical name is unknown. Since either the structures required early replacement or the tests showed failures, it is considered necessary for present purposes to include in this report only the timbers which show some resistance and can be made available in this market, or those which have been more or less widely recommended for resistance to borer attack and which do not have records which confirm the claims made for them.

Cottonwood

On account of its rapid decay and lack of strength, cottonwood has not generally been considered a structural timber, but its record at least justifies tests to determine whether it will resist the attack of marine borers.

In 1904 the Alaska Central Railway constructed a wharf at Seward, on Resurrection Bay, Alaska. It was supposed that there were no marine borers in the Bay and the wharf was built of unprotected native spruce timber. After about 18 months' service this wharf failed under a load of not exceeding 500 tons, and it was found that the piles were thoroughly honeycombed by shipworms. On account of the necessity for prompt replacement, and in the hope that the timber would better resist attack, many of the shorter spruce piles (45 feet to 70 feet) were replaced with cottonwood. No sign of attack could be found in these piles two years later when the wharf was burned.

A similar failure, in Uyak Bay, Alaska, resulted in a new wharf being built entirely on cottonwood piles, which are reported to be in good condition after 10 years' service, while in another arm of Uyak Bay a cannery wharf on cottonwood piles was in good condition after 28 years' service.

A test made by the Chicago, Milwaukee and St. Paul Railway at Seattle did not give good results. A cottonwood test pile was heavily attacked in a

few months, and a similar result was obtained in a test made by the Southern Pacific Railway at Oakland, Cal. Other tests are being made. The Northern Pacific Railway report a barked test piece to have been heavily attacked and an unbarked piece to have contained only one *Bankia* which entered through a knot.

Palmettos, Mangroves and Palms

These timbers are open to the same objections as cottonwood, but the records quoted below justify considering them, where readily available, for use in light structures. If cut off at low water decay is prevented, and much longer life than can be obtained from the pines is to be expected:

COMMON NAME	BOTANICAL NAME	LOCATION OF RECORD	SERVICE REPORT
Palmetto	Sabal palmetto	Daytona, Fla.	30 years service
Palmetto	Sabal palmetto	Nassau, Bahamas	8 years good condition
Palmetto	Sabal palmetto	Egmont, Fla.	10 years light shipworm attack
Palmetto	Sabal palmetto	Mississippi City	15-20 years light attack
Palmetto	Sabal palmetto	Pensacola, Fla.	Attack by *Martesia*
Palmetto	Sabal palmetto	Galveston, Tex.	Light attack—50 years life expected
Palm	Species unknown	Tampico, Mexico	20 years
Palm	Species unknown	Haiti	35 years
Palm	Species unknown	Santo Domingo	6-7 years
Palm	Species unknown	Guatemala	Long service
Mangrove	Species unknown	Galveston, Tex.	Not attacked
Mangrove—Black	*Rhizophora racemosa*	Guayaquil, Ec.	Long service
Mangrove—Red	*Rhizophora natalensis*	Jamaica	10-12 years
Mangrove	*Rhizophora mangle*	Haiti	20 years

A palmetto pole used for carrying test blocks at Castle Pinckney in the harbor of Charleston, S. C., contained a few *Teredo navalis* and *Martesia* after about 7 months' immersion. The *Teredo* were small and did not seem to thrive, but the indications are that *Martesia* will attack this timber as well as any other.

A considerable number of teredine borers were found in test blocks of cocoanut palm immersed for a few months at St. Thomas, Virgin Islands.

Eucalyptus

Statements are frequently made that various species of the Eucalyptus family resist attack. Some species are more durable in borer infested waters than are the pines and oaks ordinarily used for harbor works, but, as will be seen by referring to the tabulated record, page 79, none of those reported are immune from attack.

Eucalyptus propinqua and *Eucalyptus punctata* are both known in some localities as "gray gum."

SERVICE RECORD OF EUCALYPTUS

Common Name	Botanical Name	Source of Timber	Location of Structure	Report of Service
Red Gum	*Eucalyptus rostrata*	Australia	Burrard Inlet, B. C.	10-12 years F
Jarrah	*Eucalyptus marginata*	Australia	Port Moody, B. C.	16 years G
Jarrah	*Eucalyptus marginata*	Australia	Sunderland, England	5 years D
Jarrah	*Eucalyptus marginata*	Australia	Plymouth, England	20 years G
Jarrah	*Eucalyptus marginata*	Australia	English Channel	30 years G
Jarrah	*Eucalyptus marginata*	Australia	Table Bay, So. Africa	3-4 years F
Jarrah	*Eucalyptus marginata*	Australia	Mossel Bay, So. Africa	12 years F
Jarrah	*Eucalyptuc marginata*	Australia	Port Elizabeth, So. Africa	5-8 years F
Jarrah	*Eucalyptus marginata*	Australia	East London, So. Africa	2-20 years F
Jarrah	*Eucalyptus marginata*	Australia	Durban, So. Africa	10-20 years F
Jarrah	*Eucalyptus marginata*	Australia	Aden, Arabia	5-6 years F
Jarrah	*Eucalyptus marginata*	Australia	Bombay, India	5 years F
Jarrah	*Eucalyptus marginata*	Australia	Columbo, Ceylon	2 years F
Jarrah	*Eucalyptus marginata*	Australia	Chinawangto, China	2½ years F
Forest Red Gum or Grey Gum	*Eucalyptus tercticornis*	California	Los Angeles, Cal	2½ years F
Forest Red Gum or Grey Gum	*Eucalyptus tcreticornis*	California	San Diego, Cal	10 years F
Manna Gum	*Eucalyptus viminalia*	California	San Francisco, Cal	2¾ years A
Manna Gum	*Eucalyptus viminalia*	California	San Diego, Cal	10 years F
White Gum	*Eucalyptus viminalia*	Australia	Victoria, Australia	6-8 years F
White Gum	*Eucalyptus viminalia*	Australia	Port Phillip, Australia	6-8 years F
Red Ironbark	*Eucalyptus sideroxylon*	California	San Francisco, Cal	2¾ years A
Red Ironbark	*Eucalyptus sideroxylon*	California	San Diego, Cal	10 years G
Red Ironbark	*Eucalyptus siderophloia*	Australia	Port Elizabeth, Australia	5-8 years F
Red Ironbark	*Eucalyptus siderophloia*	Australia	Hobsons Bay, Australia	7 years D
Red Ironbark	*Eucalyptus siderophloia*	Australia	Brisbane, Australia	2 years A
Red Ironbark	*Eucalyptus siderophloia*	Australia	Peterson Rio	4 years F
Red Ironbark	*Eucalyptus siderophloia*	Australia	Sydney	10 years F
Sugar Gum	*Eucalyptus corynocalyx*	California	Oceanside, Cal	3 years G
Sugar Gum	*Eucalyptus corynocalyx*	Australia	Freemantle, Australia	10-15 years F
Blackbutt or Flintwood	*Eucalyptus pilularis*	Australia	Queensland, Australia	10 years F
Blackbutt or Flintwood	*Eucalyptus pilularis*	Australia	Port Elizabeth, So. Africa	5-8 years F
Karri	*Eucalyptus diversicolor*	Australia	Robbin Island, So. Africa	5 years A
Karri	*Eucalyptus diversicolor*	Australia	Table Bay, So. Africa	1 year F
Karri	*Eucalyptus diversicolor*	Australia	Mossel Bay, So. Africa	8 years F
Karri	*Eucalyptus diversicolor*	Australia	Port Elizabeth, So. Africa	5-8 years F
Karri	*Eucalyptus diversicolor*	Australia	Durban, So. Africa	1 year F
Karri	*Eucalyptus diversicolor*	Australia	Hong Kong, China	5 years F
Blue Gum	*Eucalyptus globulus*	California	16 locations in California	2½-15years F
Blue Gum	*Eucalyptus globulus*	Tasmania	Dover, England	7 years G
Blue Gum	*Eucalyptus globulus*	Tasmania	Keyham, England	7 years G
Blue Gum	*Eucalyptus globulus*	So. Africa	East London, So. Africa	3-4 years F
Blue Gum	*Eucalyptus globulus*	So. Africa	Durban, So. Africa	5 years F
Stringbark Gum	*Eucalyptus obliqua*	Tasmania	Dover, England	7 years A
Messmate	*Eucalyptus obliqua*	Australia	Victoria, Australia	8 years F
Red Stringybark	*Eucalyptus macrorhyncha* or *capitellata*	Australia	Portland Australia	14 years F
Red Stringybark	*Eucalyptus macrorhyncha* or *capitellata*	Australia	Hobsons Bay, Australia	7 years D
Red Stringybark	*Eucalyptus macrorhyncha* or *capitellata*	Australia	Port Phillip, Australia	7 years D
Red Stringybark	*Eucalyptus macrorhyncha* or *capitellata*	Australia	Tasmania, Australia	12 years F
Mountain Ash or Peppermint Gum	*Eucalyptus amygdalina*	Australia	Warranbool, Australia	12 years F
Box of East Gippsland	*Eucalyptus odorata*	Australia	Hobsons Bay, So. Africa	7 years D
White Stringybark	*Eucalyptus eugenioides*	Australia	Hobsons Bay, So. Africa	7 years D
Coast Ash, Green Top Ironbark or Silver Top	*Eucalyptus sieberiana*	Australia	Hobsons Bay, So. Africa	7 years D
Spotted Gum	*Eucalyptus maculata*	Australia	Queensland, Australia	10 years F
White or Grey Ironbark	*Eucalyptus paniculata*	Australia	Auckland, New Zealand	4 years F

F—Failed. D—Damaged. A—Attacked. G—Good condition.

Eucalyptus creba is also known as "red ironbark," and this same species is also called "gray ironbark" and "narrow leaved ironbark."

Eucalyptus patens is sometimes called "blackbutt."

Eucalyptus lencoxylon is, in a few locations, called "blue gum."

Eucalyptus gigantea is sometimes called "mountain ash."

Eucalyptus gonicalyx is sometimes called "spotted gum."

Philippine Woods

There are several timbers indigenous to the Philippine Islands which offer more or less resistance to the attack of shipworms. There is little evidence to show that any of these timbers offer a degree of resistance which approaches total immunity from attack in Philippine waters where the shipworms are very active, but it is apparent that the attack progresses slowly on some of them. It is possible that in cooler waters some of them might give long service.

There is quoted below a special report from the Public Works Officer of the Navy Department:

"Comparative Summary of Piles Used in the Philippine Islands"

"So far as can be ascertained, no very comprehensive or complete comparative tests, under exact known or pre-determined conditions, have ever been made. However, many relative tests of piling have been made, which taken together with observations of results obtained on actual work, give a fair idea of the life, durability and teredo-resisting properties of most of the native woods suitable and obtainable for use as piles in salt water. At the present time comparative tests are being conducted jointly by the Quartermaster Corps of the U. S. Army and the Bureau of Forestry of the Insular Government. These tests are being conducted on certain varieties of woods which are suitable for piling and are common and cheap enough to be used on moderate priced construction, though not possessing the teredo-resisting properties of certain other woods which are difficult to obtain and so much higher in price as to make their use almost prohibitive except in cases where durability, regardless of cost, is the controlling factor.

"The above-mentioned test is being made on piles of the following native woods: pagatpat, guijo, yacal, mangachapuy, aranga, liusin and malabayabas. As the test has been under way less than two years, it is too early to reach a full and definite conclusion regarding their relative durability and desirability. Of the varieties undergoing test, liusin and malabayabas were long ago known to be teredo-resisting, though much less durable in this respect than mancono and dungon, which are spoken of later on in this report. The last reported examination of the piles under test, made after same had been exposed a little over a year, gave the following results:

"Pagatpat.—Attacked by teredos to a considerable extent but not as much damaged as the mangachapuy, guijo and yacal. Damage superficial; teredos had reached a depth of from one inch to one and one-half inch. This wood is not common in this part of the islands but is readily obtainable in the Manila market at a fairly reasonable cost. Obtained from the southern islands, where it is plentiful.

"Mangachapuy, Yacal and Guijo.—These piles more severely attacked and damaged to a greater extent than pagatpat. Penetration by teredos deeper and holes slightly larger.

"Aranga has withstood the attacks very well so far; less damaged than pagatpat; one large pile scarcely damaged at all.

"Liusin has also withstood the attacks of borers very well, less damaged than aranga but the parts of the piles exposed to the weather have suffered considerable damage (especially the sapwood) by insects, fungi and rot, although their tops were protected by a heavy coating of asphalt. This is a common effect in liusin, especially in piles cut during the rainy season when the maximum amount of sap is present.

"MALABAYABAS piles have suffered less damage than any of the piles being tested. This result is what was to be expected as this wood ranks high among the teredo-resisting woods, though inferior to mancono and possibly inferior in some respects to dungon. Several other woods, known to be teredo-resisting to a desirable degree are either too expensive and scarce to be specified on ordinary work or too small, crooked, gnarled or otherwise defective to be suitable for use as piles.

"MANCONO (also referred to as 'Philippine lignum-vitae' and 'Philippine ironwood') is easily first among the Philippine woods as regards teredo-resisting properties. This wood is very heavy, hard and dense, has a specific gravity of 1.236 to 1.296 and the heartwood is credited with being practically immune from the attacks of marine borers and insects. Even the sapwood is teredo-resisting to a high degree, and piles of this wood which have been in place in salt water for over 20 years were found to have their sapwood only lightly attacked by teredos to a depth of about ½ inch. Mancono piles in use more than 60 years in salt water are still in excellent condition in several places in the southern islands. This wood is so scarce and expensive that but little of it reaches the Manila market and its estimated price for moderate size piling, 30 to 40 feet in length, is from $4 to $5 per lineal foot. Of the teredo-resisting woods obtainable, dungon was supposed to rank next to, but considerably below, mancono, but recent experiments and observations indicate that malabayabas is probably equal and possibly superior to dungon but is more expensive. Dungon piles of ordinary size at present are estimated to cost $1.20 to $1.40 per lineal foot. Malabayabas piles of similar size are estimated to cost about $2 per lineal foot. Malabayabas is closely related to mancono botanically and apparently approximates same in nearly all general physical properties. Neither of these woods is common in the Manila market and they are obtained from points further south."

As is the case in other tropical countries these timbers have several local names, and their scientific nomenclature is not fully established. The following information as to common and scientific names was obtained from Bulletin No. 14 of the Bureau of Forestry (1916) of the Philippine Government:

Pagatpat, *Sonneratia pagatpat* Blanco is also known as buñgalon, ilukabban, lukabban, palalan, pedada, pirara, palapat, and patpat.

This timber is found in the largest quantity in the mangrove swamps of the Island of Mindanao but has a wide distribution in the archipelago. It is a fairly hard straight grained wood, easy to work, but it rusts nails and other iron fastenings.

Its price in 1916 varied from 50 to 95 pesos per thousand.

Mangachapuy, *Hopea acuminata* Merr. is also known as bangoran, baniakan, barosingsing, dalingdiñgan, kaliot manggachopui, manggasinoro, siyan and yakal.

Yacal, *Hopea plagata* Vid. is also known as banutan, batik, dalingdiñgan, gisok-gisok, haras, kaliot, malium, paniggaian, quiebra-hacha, sallapugud, sarabsaban, sapluñgan, siakal, siggai with various adjectives, and taggai.

The wood of the two species of this genus which are very similar is hard, tough, heavy, and has a sharply crossed grain that makes it hard to split, although it saws with a clean surface.

The price in 1916 varied from 60 to 120 pesos per thousand.

Guijo, *Shorea guiso* Blanco is also known as antam, arombi, barusingsing, batik, bitik, dagingdiñgan, daniri, giho, gisek, gisik, gisok, giso, kuriat, kuribu, pamayanasen, pisak, pisek, sarrai, sigai, taggai and yamban.

The wood is moderately hard and tough, with a cross grain difficult to split; is liable to split and warp if not carefully seasoned; is not hard to saw but is difficult to work otherwise.

The price in 1916 varied from 45 to 120 pesos per thousand.

Aranga, *Homalium luzoniense* F. Vill is also known as arañgan, kamagahai, kamagahi, malatumbaga.

There is little difference between the four described species of this genus. The wood is hard; heavy with a straight or slightly crossed grain; seasons without much checking or warping; is hard to saw but otherwise easy to work.

The price in 1916 varied from 110 to 180 pesos per thousand.

Liusin, *Parinarium corymbosum* Miq., is practically indistinguishable from the one other described species of the genus. The local names for timbers of this genus are: aningat, bakayan, barit, binggas, binggau, boñgog, botabon, duñgon-duñgonan, gunaimai, ginaiang, kagemkem, kamilitiñgan, kangkañgan, kapgañgan, karatakat, kulatiñgan, lankañgan, langog, laiusin, lumuluas, malaigang, malapiga, malapuyan, maluklik, mantalina, mantaliñgan, matamata, pantoy-use pasak, sabougkaag, salifuñgan, salutin, sarañgan, sigaadan, tabon-tabon, takdañgan, tapgas, and uas-uasa.

The wood is hard; very heavy; grain straight or slightly crossed; seasons without much checking but warps considerably; very difficult to work, being notorious for the rapidity with which it dulls tools. Most mills refuse to saw or plane it. The Philippine records do not show that this timber contains silica, but the description would seem to indicate a resemblance to Angelique and Manbarklak.

The price in 1916 was from 100 to 140 pesos per thousand.

Malabayabas, *Tristania decorticata* Merr, is one of three species of the genus which are commonly grouped together commercially, since there is no difference between them from that standpoint. It resembles and is often substituted for mancono.

The local names for words of this genus are: adios, anigad, bunglo, busag, diñglas, hublas, malumbayabas, malapiga, taba, tiga and tinadan.

The wood is very hard and heavy with a slightly crossed grain; seasons without much checking but needs to be carefully piled to prevent warping; hard to work but is not especially hard on tools.

The price in 1916 ranged from 70 to 130 pesos per thousand.

Mancono, *Xanthostemon verdugonianus* Naves, is locally known as malapiga, magkono, mangkono, tamulanan, tiga, Philippine ironwood, Philippine lignum-vitæ, and palo de hierro.

It is a low branching tree with seldom more than 10 meters of clear trunk. The wood is very hard and heavy, with the grain always crossed and frequently twisted and so fine that it can be burnished almost like metal. It does not warp badly but does heart check to some extent. The quantity available is not large, and the prices in 1916 were from one to one and one-half pesos per cubic foot, though it is estimated that the timber could be delivered on the beach for about 0.22 pesos per cubic foot.

Dungon, *Tarrietia sylvatica* Merr, and Dungon—late *Heritiera littoralis* Dry, are practically indistinguishable species, the former growing in high and the latter in low land near the coasts. The local names are barit, bayagkabayo dumon, duñgul, magayan, malarungon, palogapig, paloñgapoi, paronopin and paronapoi.

The wood is very hard, tough and flexible but not resilient; is heavy and often contains stony deposits in old knots and heart cracks; the grain is crossed and often curly; logs split deeply in seasoning; it is very difficult to work and dulls tools badly even when no stony deposits are encountered.

The price in 1916 ranged from 150 to 200 pesos per thousand.

FIG. 19—SECTION OF JUCARO PILE FROM DOLPHIN OF TEXAS OIL COMPANY, MATANZAS, CUBA

Placed, 1919—Removed, 1923

Turpentine Wood

Australian "Turpentine Wood," *Syncarpia laurifola* appears to be very resistant to attack but not entirely immune. The sap wood is subject to attack, but in most locations the *teredo* and *limnoria* do not seem to progress beyond that point. This attack on the sap wood is shown as "slight attack"

in the following table, which shows service records of this timber:

Victoria, B. C.	18 years	Piles slightly scarred
Bombay, India	6 years	Slight attack by Pholads
Madras, India	2½ years	Slight attack by Pholads
Madras, India	12 years	Failed
Kelue, Formosa	4 years	Good
Madras, India	12 years	Failed
New South Wales harbors	30 years	Failed
Port Hunter, Australia	6½ years	Good
Sydney (6 reports)	10-48 years	Slight attack
Durban, South Africa	5 years	Good
Calcutta, India	4 years	Good
Yokohama, Japan	2 years	Good
Adelaide, Australia	30-40 years	Failed
Coff's Harbor, Australia	1 year	Attacked
Brisbane, Australia	15 years	Failed
Auckland, N. Z.	9 years	Slight attack

It seems entirely possible that this timber would give long life in northern waters. It can be obtained in long lengths and is a good structural timber.

Totara

Podacarpus totara, a New Zealand timber, shows well in the few definite records available. It was one of the timbers tested at Hobson's Bay, Australia, and after 7 years was in good condition: in Auckland, N. Z., an inspection showed piles to be in good condition after 20 years' service, but to have failed at the end of 35 years.

Other Timber

Several West Indian and Central American timbers have been reported from time to time as being able to resist attack, but records from other points show failures. Four examples of reports on timbers said at some points to be resistant are as follows:

COMMON NAME	BOTANICAL NAME	SOURCE	LOCATION	CONDITION
Zapotechico, chicozapate, nasewood, nispero, sapodilla	*Achras sapota*	Central America	Puerto Cortez	6-10 yrs. Failed
Quiebra-hacha or quebracho	*Aspidosperma quebracho*	Central America	San Salvador	Quick attack
Jucaro prieto, black jucaro, or arare	*Bucida* or *Terminalia* } *buceras*	Cuba	Matanzas, Cuba	2 yrs. Failed
Sabicu, jigue moruro de costa or chocolate mahogany	*Lysiloma formosa* or *Lysiloma sabicu*	Cuba	Mariel, Cuba	1 yr. Failed

Jucaro is reported by the Florida East Coast Railway to have given good service, but to be difficult to obtain. Fig. 19 shows a section of a pile from the foundation of the marine railway at Matanzas, Cuba, after less than 4 years' service.

Greenheart—*Nectandra rodioei,* is a timber from Dutch Guiana and British Guiana which has given excellent service in many European harbors and has been much advertised. The service records collected are as follows:

Trinidad	10-15 years	Failed
Georgetown, B. C.	20-25 years	Failed
Groningen, Holland	11 years	Slight attack
Friesland, Holland	18 years	Slight attack
Harlingen, Holland	9 years	Good
Gostmahorn, Holland	18 years	Slight attack
Nieuwe-Zylen	14 years	Good
Ymiden, Holland	12 years	Good
Vlessingen, Holland	10 years	Slight attack
Vlessingen, Holland	16 years	Good
Walsoorden, Holland	10-21 years	Slight attack
Walsoorden, Holland	29 years	Good
Portree, England	25 years	Failed
Salem, England	4 years	Attacked
Blackmill Bay, England	11 years	Damaged
Liverpool, England	38 years	Good
Liverpool, England	61 years	Good
Holyhead, England	20 years	Damaged
Yarmouth, England	25 years	Damaged
Zeebrugge, Belgium	6 years	Slight attack
Ostend, Belgium	16 years	Slight attack
Dunkerque, France	24 years	Slight attack
Havre, France	13 years	Good
Wich, Scotland	2-4 years	Attacked
Bell Rock, Scotland	19 years	Slight attack
Methil, Scotland	24 years	Failed
Methil, Scotland	14 years	Attacked
Methil, Scotland	11 years	Failed
Sunderland, England	35 years	Failed
Southampton, England	10 years	Attacked
Plymouth, England	30 years	Failed
Port Elizabeth, Australia	8 years	Damaged
Port Elizabeth, Australia	12 years	Failed
Bombay, India	15-20 years	Failed
Calcutta, India	10 years	Failed
Java	5-10 years	Failed
*Ganges River	10 years	Failed

In tropical waters Greenheart does not have an especially good record, but in waters of lower temperatures its record is better, although failures in 15 to 20 years are reported. It is supposed that the protective principle in this timber is an alkaloid known as "beberine."

Angelique and Manbarklak—The protective element in all the above-mentioned timbers is supposed to be chemical, except in the case of the palms where it is probably due to the fibrous structure of the wood. Two timbers from Dutch Guiana are now being exploited which depend on their mechanical qualities for their resistance. Manbarklak, *Lecythis ollaria,* and Angelique, *Dicorynia paraensis* contain minute particles of silica which are said to prevent the operation of borers.

Only two test records of Manbarklak, and one of Angelique, are available. At Vlessingen, Holland, Manbarklak is reported to be in good condition after 18 years' service, and in the Saramacea Canal, Dutch Guiana, after 17 years' service. A test piece of Angelique submerged at Buklinsen City, Dutch

*This structure was in fresh water, but was destroyed by a species of fresh water *teredo.*

Guiana, with a similar piece of Greenheart was in good condition after 7 years, while the Greenheart was totally destroyed.

On account of the failure of the Greenheart used in the locks of the Panama Canal, the authorities of the Canal Zone are investigating a number of woods and have tested the above-mentioned woods to determine the amount of silica as compared to the common timbers with the following results:

Buch	1.10% Ash	0.02% Silica
Birch	0.26% Ash	0.01% Silica
Oak	0.51% Ash	0.01% Silica
Angelique	2.05% Ash	0.93% Silica
Manbarklak	1.40% Ash	0.52% Silica
Greenheart	0.08% Ash	0.04% Silica

A microscopic examination shows that the particles of silica are evenly disseminated through the timber. This timber is also said to offer considerable resistance to decay.

Conclusions

Cottonwood is available on the Pacific and Gulf Coasts and, subject to its structural limitations, has enough promise to justify thorough test of its ability to resist borers, but it should not be depended on until such tests are made and the limitation for its use established.

Unless Turpentine wood, Angelique or Manbarklak supply the necessary qualities, it does not seem that there is any foreign timber which has a service record showing immunity from attack under all conditions.

From recent reports it appears that there is a variation in the silica content of these timbers, and tests are required to determine the necessary silica content so that it can be specified.

Several timbers which have a fairly good record in cool water do not give as good service in the tropics. Some of these timbers are either expensive to produce, available only in limited quantities, or subject to quick destruction by decay above the water level.

It appears improbable that until native timbers which require protection are higher in price it will be economically desirable to use tropical timber for harbor works in northern harbors of the United States.

In Pacific Island, Gulf and Caribbean harbors, where only eight or ten years' average life is obtained from creosoted timber, further study may show that some of these timbers are economical.

CHAPTER VI

PROTECTION AGAINST BORERS

The protection of timber in salt water against the attack of marine borers has been attempted by many methods since the earliest historic times. The earliest attempts were probably those of the Phoenicians and Trojans who sheathed their galleys with lead. Most methods used have been unsuccessful from the standpoint of permanence, though several of them have resulted in materially increasing the life of timber in borer-infested waters.

Many times structures are built for which it is not necessary or desirable to secure the longest possible life, and frequently financial limitations are such that some less expensive protective method than the one most desirable must be adopted. These conditions make a knowledge of the less expensive and generally less efficient methods just as important as that of the best methods.

Service records and records of tests have been assembled and selected from a very exhaustive report prepared by Mr. A. K. Armstrong at the Forest Products laboratory, U. S. Department of Agriculture, in 1913; from the reports on "Deterioration of Structures in Sea Water," 1920, 1921 and 1922, published by the Institution of Civil Engineers of London; from a report "Paeleorms og Paelekrebs Angreb ved Skandinaviens Kyster" 1918-19 by the Scanadinavian Engineering Societies; from the reports of the San Francisco Bay Marine Piling Committee, 1920, 1921, 1922 and 1923, and from special reports by various government agencies, railroads and others. In a number of cases it has been possible by correspondence to bring the records found in the earlier reports down to 1922 or 1923. The section dealing with creosote impregnation was prepared in collaboration with Dr. H. von Schrenk.

For convenience the various methods of protection are divided into several classes:

I. BARKS

Barks ordinarily contain certain oils and acids, not present at least in as large quantity in the wood itself, and which are thought to act as repellants to the borers. The fibrous structure of the bark undoubtedly also makes attack by borers more difficult.

To be of value as a protective agent bark must be unbroken and no access to the timber itself must be offered. This makes necessary extreme care in handling and frequently banding before the pile is handled or driven. It is often desirable to cover knots and other breaks in the bark with a sheet metal which will last as long as the bark itself. (Fig. 20).

From about 20 reports the following are selected as typical:

1. Portsmouth, N. H. Piscataqua River Bridge, Boston & Maine Railroad. In water infested with *Limnoria*, bark was an effective protection "except at knots and other places where bark was stripped before driving." The attack at this point is not very heavy.

2. Norfolk Navy Yard, Norfolk, Va. Oak piles cut in January "resisted four or five years or until bark rubbed or chafed off."

3. Wilson Line Pier, Hoboken, N. J. Oak piles driven in 1912 had bark still tight in 1922. Attacked by *Teredo navalis* in knots and blazes only. The borer attack is light in this location.

4. White Pass & Yukon Ry. Pier, Skaguay, Alaska. Hemlock piles winter cut with tight bark last about seven years, two to three times as long as unprotected piles. Both *Limnoria lignorum* and *Bankia setacea* are present in considerable numbers.

II. BUILT UP PILES

Square cores sheathed with one or more layers of boards with or without intervening layers of tar paper, hair, etc., have been thought to be resistant. This is not correct, since the boards can be readily destroyed a layer at a time, and in case of the molluscan borers there is no protection at all unless the different layers are separated by some impenetrable material. *Martesia*, at Pearl Harbor, H. I., bored through board sheathing and a layer of tar paper.

The most that can be said for this method is that if tar paper, felt, or similar material is used between the layers, the life of the pile will be slightly extended. If creosoted boards are used for sheathing an otherwise unprotected core, they will undoubtedly materially lengthen the life of the pile, to an extent dependent on the rapidity with which the creosote leaches out of the thin timber. The Charleston (S. C.) Dry Dock and Machine Company sheathed the pontoons of their floating wooden dry dock with a layer of felt and one-inch boards impregnated with 12 pounds of creosote per cubic foot. This dock was built in 1919, and the pontoons were found in 1923 not to have been attacked, although both *Limnoria* and shipworms are very destructive at this point.

III. CHARRING AND TARRING

Charring has been used as a means of protecting timber from the attacks of marine borers since the earliest historic times, but used alone there is nothing in the service records to indicate that this method has appreciable value as a protection against borers. When timber is charred and some additional protective method is used, the quality of protection seems to depend largely on the efficiency of this second element. From service records covering about 20 structures the following are typical:

1. Navy Yard, Norfolk, Va. Piles with thoroughly charred surfaces lasted nine years with some shipworm attack.

2. Charleston, S. C. Pine piles charred and impregnated with wood creosote lasted from 1883 to 1890, seven years.

3. Alabama, Mississippi and Louisiana. The New Orleans & Mobile Railroad treated between 400 and 500 piles by charring with coal tar burnt on them, brush coated with creosote and covered with coal tar varnish. They lasted about eight years.

4. Thana District, India. Khair piles well charred lasted 40 years as against a usual life of 25 years for unprotected timber. This is a location where shipworm attack is light.

5. Hobart, Tasmania. Blue gum piles coated with tar, charred and while hot covered with thick coal tar gave service of from 25 to 35 years as

FIG. 20—SECTIONS OF BARKED AND UNBARKED COTTONWOOD TEST PIECES IMMERSED AT PIER 1, NORTHERN PACIFIC RY., SEATTLE, SEPTEMBER 27, 1923 AND REMOVED JANUARY 28, 1924

against about 12 years for unprotected timber. Here again the shipworm attack is not heavy.

IV. PILE COATINGS

In the unpublished report of the Forest Products Laboratory a pile coating is defined as "Protection that is an integral part of the wood's surface, becoming so by a slight penetration, which through its content of a substance chemically harmful or disagreeable to the marine wood borers prevents them from entering the timber." Generally this method of protection is inefficient except for temporary structures, because the protective element is leached out of the thin coating by the sea water or the coating itself destroyed by abrasion within a very short time.

Pile coatings are usually inexpensive and need be applied only to those portions of the piles exposed to attack; some of them are useful for structures requiring temporary protection or for structures for which funds are not available in a sufficient amount to permit the use of a more durable method.

The following reports are recorded for the positive or negative information which they contain:

1. Tar

Eight reports of the use of tar in foreign harbors are available. None of them show an increase in the length of life of timber for more than a few months, and this result might readily be accounted for by the time of year at which the structures were built.

2. Carbolineum Avenarius

Carbolineum was supposed to be a high boiling creosote oil containing chlorine, and was manufactured by a secret process.

The Forest Products Laboratory received a supply of this material for test from the Carbolineum Wood Preserving Company of San Francisco. This material did not conform to the analysis furnished by the American agent of the company but was used for the preparation of Douglas Fir test pieces twelve inches diameter and eight feet long. Three coats were applied at intervals of four and twenty-three days respectively, and placed in harbor waters as indicated below. The cost of material at this time (1910) was about seven cents per linear foot of pile treated.

LOCATION	KIND OF BORERS PRESENT	LENGTH OF TEST	CONDITION OF TEST PIECE
San Francisco, Cal.	*Limnoria*	2 1/12 years	Attacked
San Francisco, Cal.	*Limnoria* and *Bankia*	2 1/6 years	Severe attack
San Diego, Cal.	*Limnoria*	4 years	Destroyed
San Diego, Cal.	*Limnoria* and shipworms	4 1/12 years	Destroyed

A test using 12-inch by 12-inch yellow pine sticks treated with two or three coats was started at Savannah, Ga., in 1908, the pieces being placed so that they were uncovered at each low tide. These test pieces showed no attack at the end of four years, but were destroyed at the end of 14 years.

A report from Tampico, Mexico, shows that timber painted with Carbolineum was unattacked after six months, and another from Manzanillo, Mexico, states that timber similarly protected was destroyed in six months.

A report from British Columbia states that the material is "useless."

An opinion from Genoa, Italy, is to the effect that Carbolineum increases the life of timber about 10 per cent, and the Chief Engineer, State Harbor Administration, Andenaes Westermalem, states that Carbolineum and Sotor protect only until the material is leached out or worn off.

3. Sotor

Sotor is a paint manufactured by a secret process by the same company that manufactures Carbolineum Avenarius, and is sold as a pile protection. The cost is about the same as that of Carbolineum.

In 1910 the Carbolineum Wood Preserving Company treated twelve test pieces 14 inches diameter by 8 feet long with Sotor, six of which were placed at San Diego and six at San Francisco by the Forest Service. The reports of inspection at San Francisco show that all pieces were destroyed by *Teredo* and *Bankia* before 1920, and those at San Diego show the average life to have been 3.6 years. All of the sticks showed some attack within two years and eight months.

The City and Harbor Engineer of Svendborg, Denmark, states that he has found Sotor to be "protective to some extent," while the District Engineer at Vardö, Finmark, states that it does not give lasting protection.

4. Copper Paints

Copper paints have had a wide use for the protection of the bottoms of wooden vessels where frequent docking and renewal is possible, but they have been used very little for the protection of structures. Records of the result of the use of these paints on vessels and on the wooden buoys of the Lighthouse Service indicate that they can be expected to give efficient service for from four to six months in badly infested water, and a similar service could probably be expected on piles.

5. Kennons Teredo Proof Paint

This material is said to be composed of creosote, coal tar and iron oxide combined with various substances which tend to prevent the germicidal properties of the creosote being leached out by salt water. It was placed on the market about 1896.

A Forest Products Laboratory analysis showed 40 per cent tar, 50 per cent oil similar to Mond Producer Oil, and 10 per cent ferric oxide.

Record of five observations by the War Department, and six by the Forest Service, show no case in which the timber protected by this paint successfully withstood attack. One report of satisfactory service for a period of two years is made by the Craig Shipbuilding Company of Los Angeles.

6. Miscellaneous Coatings

Reports on service and tests of the following materials are available from 38 locations in the United States, Holland, Russia and South Africa:

Fish oil and tallow mixed
Red lead
Resin and tallow mixed
Verdigris
White zinc
Childerson's Teredo Proof Paint
Mott Fireproof Paint
Gimle Teredo Proof Paint

Asphalt
Marine Cement
Portland cement and unknown ingredients
Gilberts' Paint
Composition of Brinkerink
Composition of Classen
Composition of Ryhuyk
Chrome green
Metallic paint of Classen
Paraffine varnish
Mixture of coal tar, oil of vitriol, etc.
Tar mixed with powdered glass
Solignum
Solignum and pitch varnish
Teredocide

None of the reports show appreciable protective value except the following:

(a) Test pieces treated with Childerson's Teredo Proof Paint immersed at the Pensacola Navy Yard, Fla., in March, 1896, were unattacked at the end of six months, while unprotected pieces were completely riddled.

(b) One out of three pieces of pine treated with Solignum and immersed at Taube Bay, South Africa, was unattacked, while the other two were attacked.

(c) One test piece of teak and one of jarrah treated with Teredocide at East London, South Africa, in 1910, were unattacked after two years, where unprotected pieces of pine and yellow wood were penetrated two inches by shipworms.

V. PILE ARMORS

Under this heading are classified those methods of protecting wooden piles from borer attack which depend wholly or principally on some mechanical method of preventing the borers from coming in contact with the timber. This result is generally obtained by sheathing the pile in sheet metal or fabric which has been specially treated, or by casing it in metal, or other pipe or concrete. Any such protection must cover the pile from a point below the possibility of scour to a point above extreme high water.

1. Steel or Iron Sheathing

Sheet steel or iron sheathing is seldom used because of its rapid corrosion. Timber is immune from attack as long as the sheathing is sound, but this is seldom the case for more than from three to six years, even when the metal used has considerable thickness.

2. Zinc Sheathing

About 12 structures are recorded where sheet zinc (Nos. 9 to 14) has been used in the United States and Europe. The material was not reported to be a success as a permanent protection in any of the European structures. The Louisville & Nashville Railroad reports that piles driven in a bridge over Bay Biloxi, Miss., were protected by zinc, some as heavy as No. 9; felt was placed between the metal and the piles, but in spite of this double protection the piles were heavily attacked in eight years. Zinc sheathing undoubtedly prolongs the life of piles on which it is used, but the records do not indicate that it is an economical material for sheathing.

3. Muntz Metal

Muntz or "yellow" metal has been widely used for pile sheathing in harbors in many parts of the world. It is an alloy generally 60 per cent copper and 40 per cent zinc, and it is stated that the alloy must be homogeneous, else electrolytic corrosion will remove the zinc.

In 1871 the New Orleans & Mobile Railroad reports a typical installation at Bay St. Louis, Miss. Muntz metal sheathing was placed over a layer of felt. The first failures were caused by bottom scour which uncovered the unprotected pile, and later holes appeared in the metal. It is reported to have been "thinned by decomposition in one year" but not to have shown very many holes in six years.

The cost of this method in South Atlantic and Gulf ports in 1906 was about $1.20 per foot of pile protected.

Reports from foreign harbors are as follows:

New South Wales Harbors	Unsatisfactory in most cases.
Rio de Janeiro, Brazil	Piles destroyed in 10 years where unprotected piles lasted 2 years.
Durban, South Africa	Not a permanent success.
Queensland Harbors	Piles destroyed—10 to 15 years.
Victoria, Australia	Piles destroyed — average life 20 years.
Brisbane, Australia	Sheathing destroyed—average life 20 years.
Wellington, New Zealand	Jarrah piles good after 30 years.

The discussions in the British reports show considerable difference in the opinions as to the durability of this alloy, which seem to have been caused by variations in the quality of the metal.

4. Copper Sheathing

The high initial cost of copper sheathing is a decided drawback to its use, both because of its first cost and because this metal has sufficient value to make it worth stealing by harbor thieves. Like all other sheathings, copper is subject to abrasion and is readily torn by drift. It does not, however, corrode as rapidly as most other metals, and in the reports listed below the cause of failure is generally stated to be theft or abrasion by drift. The following service records have been obtained:

LOCATION	KIND OF SHEATHING	AGE	REMARKS
Admiralty Piers, Jamaica	16 gauge copper	35 years	Good condition
Port Antonio, Jamaica	Copper	15 years	Destroyed
Southend, England	Copper	11 years	Piles driven in 1833. In 1844 copper very thin and brittle
Rio de Janeiro, Brazil	Copper	10 years	Piles destroyed
East London, South Africa	Copper	20 years	Good condition
Durban, South Africa	Copper		Not a success
St. Thomas, Virgin Islands	20 gauge copper	8 years	3 out of 128 piles have sheathing damaged by boats, all others good

The Bureau of Lighthouses report having used copper sheathing on many lights and beacons in the Gulf of Mexico, and state that this method of protection was very successful until the sheathing was destroyed by a hurricane.

A wharf with copper sheathed piles was built by the Southern Pacific Railway at Tacoma in 1877. This wharf was removed in 1898 and the copper found to be in good condition, although it showed some corrosion. The piles had not been damaged and were covered by a heavy incrustation which seemed to be a copper salt. Forty-four of these piles were redriven in a bridge on the Burnett Branch of the Northern Pacific Railway in 1900 and are still in service (October, 1922) without any sign of decay.

Copper is undoubtedly a valuable sheathing material, but there is almost no data to show its rate of corrosion, since few of the reports give the thickness of the copper used. Further study should be given to the question of the rate of corrosion and to determine the nature of the deposit on the piles, as in the report of the Northern Pacific Railroad, and its value as a protection against borers.

5. Cast Iron Casings

Cast iron deteriorates very slowly in salt water and therefore it is an efficient material for the protection of timber piles, although its first cost is high. Like other pile armors it is entirely valueless if the timber is not completely covered for the full depth of the zone of attack.

The Louisville & Nashville Railroad has used, for the protection of existing structures, a casing made in semi-circular sections which are bolted together. Care is taken to get the casing below the possibility of scour. It is filled with sand and capped with cement mortar so that the loss of sand which would indicate breakage or undercutting can be readily determined by removing the cap.

The Bureau of Lighthouses has made a considerable use of cast iron water pipe as casings. They report seventy-eight structures in the Gulf of Mexico waters in which cast iron pipe casings were used. These structures were built between 1896 and 1921, more than fifteen of them before 1907. The casing was placed after the piles were driven and before the dock was constructed. After the casing was in place it was filled with 1 to 3 cement mortar. The last inspection by diver was in 1914, and all structures were found to be in excellent condition, and so far as general non-diver inspections in 1921-22 could show, no deterioration had taken place in the iron, except in one structure in which the iron had slightly deteriorated, although some of the piles had decayed above the top of the pipe.

Cast iron pipe filled with sand or mortar is not easily broken, and since it is not likely to deteriorate seriously for many years, it gives a very efficient protection. If the timber piles are also creosoted or otherwise preserved from decay as was done by the Bureau of Lighthouses in its pier at Guantanamo, Cuba, and elsewhere, it would seem that a very long-lived structure would result.

6. Vitrified Pipe Casings

Vitrified pipe casings have been used to a large extent along the Gulf Coast and to some extent on the Pacific. They are placed and filled with sand in the same manner as cast iron pipe, and are just as efficient so long as they are unbroken, since good vitrified pipe does not appreciably deteri-

orate in salt water. This type of casing is very easily broken and should not be used where there is water movement such as waves or current, since under these conditions there is great chance of breakage by drift. Railroads on the Gulf Coast report structures in good condition after 20 years' service in still water, while in San Francisco Bay such protection only lasted two years, and in Pensacola the casings, which cost $10,000, on the piles of a new wharf, were broken within 30 days.

7. Perfection Piles

The "Perfection" process of pile protection which was used to a very considerable extent in the Puget Sound district was an attempt to build up a pile armor which would be cheaper and more effective than metal sheathing.

To form the coating the pile was wrapped in burlap in 8-inch wide strips which had been thoroughly soaked in a hot mixture containing:

2	barrels	crude asphalt
1	barrel	slaked lime
50	pounds	rock salt
100	pounds	sulphur
25	pounds	marble dust
3	cubic feet	fine, dry, clean sand.

The pile was wrapped spirally in such a manner as to obtain two thicknesses of burlap which would result in a total thickness of about one-half inch. There was placed over the burlap a spiral wrapping of 12 or 14 gauge galvanized wire fastened with staples, the wires being three inches to five inches apart.

Perfection piles were used in the construction of the Eureka Dock at Tacoma, Wash., in 1895, and when this dock was removed in 1910 a considerable number of the piles were in good condition. This type of pile was used in five docks at Seattle, and the result of an inspection of the remaining Perfection piles made in December, 1922, and January, 1923, is shown below:

LOCATION	DATE BUILT	ORIGINAL NO. PERFECTION PILES	NO. PERFECTION PILES IN SERVICE AND GOOD CONDITION
Pier No. 1........	1900	1,300	75
Pier No. 2........	1902	1,690	30
Pier No. 3........	1901	1,085	4
Pier No. 4........	1902	1,358	36
Pier No. 5........	1901	1,379	49
		6,812	194

The Coaling Pier and the Main Station Pier at the Puget Sound Navy Yard were built on Perfection piles between 1901 and 1904, and the two piers still contain 332 of these piles, a slightly larger percentage than in the Northern Pacific piers. This is accounted for by the better protected site at the Navy Yard and perhaps the fact that some of these piles were further protected by tarred or creosoted battens. It is, however, stated that the coating on most of these piles remaining is broken and that the piles have been attacked (Fig. 21).

The Perfection pile process gave complete protection to the timber as long as the coating was unbroken, but the coating was too fragile to result in a high percentage of survivals after a period of years.

8. Moran Process

The Moran Process is said to be a combination of impregnation and sheathing. The piles are coated with a mixture of gilsonite reduced with creosote to which is added iodide of arsenic applied at a temperature of 375 deg. Fahr. After 24 hours a second coating of heavy dense asphalt or gilsonite is added, and in it a wire mesh cloth of heavy wire is imbedded. It is claimed that a considerable penetration of the toxic ingredients is obtained in the wood.

This process was developed in San Francisco, and the first use of piles so protected recorded by the San Francisco Committee was in 1913 when 50 piles were driven by the San Francisco-Oakland Terminal Railways, but no service record is available. In 1921 the Southern Pacific Railway drove 102 piles in the Georgia Street wharf at Vallejo and 18 in a dolphin at the same place, protected by this process. The cost of the treatment to the Southern Pacific was $1.215 per linear foot of pile treated, which is about double the cost claimed by the company. Twenty-six piles were also driven in the Virginia Street wharf of the City of Vallejo in 1922. Service records of these structures will be awaited with interest.

9. Paraffine Paint Process

This process has had some use in San Francisco Bay since 1889, and while a considerable number of piles protected by this method have been used, there seem to be no service records available from the older structures.

The process is described in the following specifications furnished the United States Forest Service in 1911:

> "The piles, having been delivered in some convenient place for coating, will first be barked the distance they are to be protected and all knots and projections on the above mentioned part of the pile removed.
>
> "The barked portion of the pile will then be given a heavy coat of P. & B. Pile Paint, care being taken to fill all checks and to cover all surfaces thoroughly. P. & B. Pile Covering will then be closely fitted around the pile, and all laps well cemented with P. & B. Paint and nailed with 1¼-inch galvanized nails, not more than 1½ inches between nail centers. Where necessary a double row of nails will be driven. This pile covering will then be given a heavy coat of P. & B. Asphalt, into which will be embedded a close fitting lagging of redwood battens, 2 inches by 7/16 inch, nailed on alternate edges with six penny galvanized wire nails, not more than 9 inches between nail centers, ends of battens to be double nailed. This lagging is then to be given a heavy coat of P. & B. Asphalt, care being taken to fill all spaces between the battens and to give the finished surface as smooth an appearance as possible.
>
> "As above finished the pile will be ready for removal and driving."

Concerning the "Pile Covering" the following information was given:

> "The material used by us is a heavy jute burlap, weighing either 10 or 15 oz. to the yard, 33 inches wide, according to the engineers' specifications—the heavier weight being that preferably used. This is saturated and coated with a specially prepared asphalt and backed with saturated felt. The heavy grade pile covering weighs about 60 pounds to the 100 square feet, while the lighter weighs about 45 pounds to the 100 square feet."

The exact nature and composition of the paint and the asphalt are, quite naturally, not given. The asphalt is understood to be applied to the burlap cold.

It is reported that between the years 1906 and 1909, 3600 piles protected by this method were driven by the San Francisco-Oakland Terminal Rail-

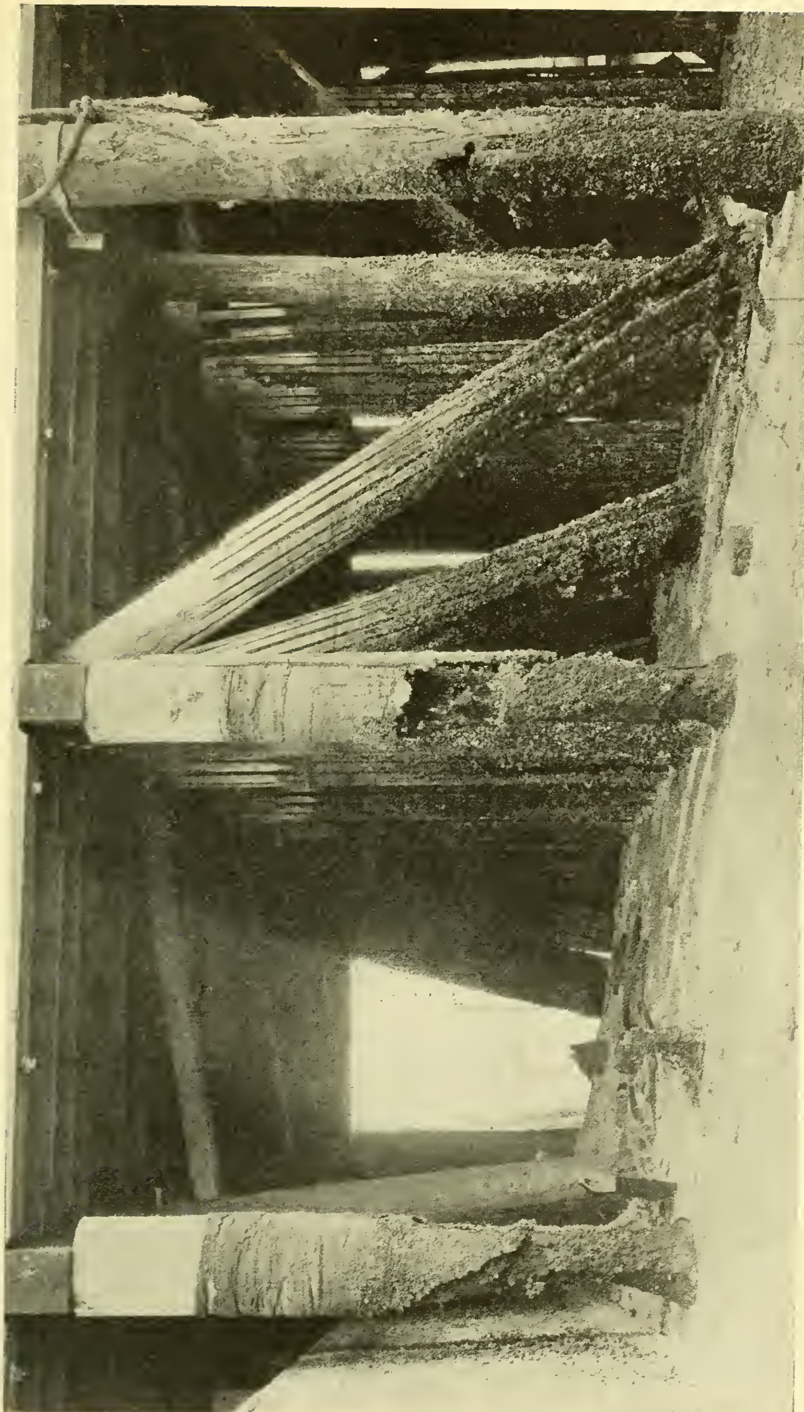


FIG. 21—PERFECTION PILES DRIVEN IN 1903 IN COAL WHARF AT THE PUGET SOUND NAVY YARD.

way. The first 500 under the train shed were replaced in from two to three years, while the other 3100 lasted from five to seven years.

Recent installations of piles protected by this method have been 89 piles in the Georgia Street Wharf at Vallejo; 18 in a dolphin by the Southern Pacific in 1921; 252 piles in a trestle across Petaluma Creek in 1920 by the Northwestern Pacific Railway and 2994 in the wharf at Eckley Station by the Grangers Business Association in 1920-21. The cost of protection of the piles used by the Northwestern Pacific is stated to have been 62 cents per linear foot of pile covered.

10. Columbia Paint Process

This process is similar to the Paraffine Paint Process, using paint manufactured by the Columbia Paint Company. In 1913-14 the San Francisco-Oakland Terminal Railway drove 130 piles protected by this process, of which 30 were replaced in 7 years and the remainder are still in service. In 1918, the Union Construction Company drove 950 of these piles in 6 different structures in their shipyard at Oakland, all of which are said to be still in service.

11. Argentine Quebracho Process

This process is similar to the two preceding, except that "Argentine Quebracho Commercial Paint" is used instead of Paraffine or Columbia paint. Three hundred and eighty piles protected by this compound were driven in various structures at the Mare Island Navy Yard in 1920-21.

There are several other processes on the market similar to the above, all depending on the strength of some proprietary compound, the composition of which is usually unknown. The danger in the use of such compounds is evident.

The processes described above have a distinct place in the general scheme of protection. They are generally less expensive than some other more efficient methods and under some conditions will give as long a life as is desired for a structure. Their relative economy increases with the decrease in the proportion of the pile which must be protected, since a pile with deep penetration and a small length exposed to attack requires only a small amount of protection, while protection by impregnation requires treatment for the entire length of the pile.

12. "Scupper Nailing"

Attempts to protect galleys from borer attack by driving their hulls full of nails were made in ancient time, and this method of protection for structures has been used intermittently in Europe since the eighteenth century. The protection given by the nails results not only from covering a large part of the surface of the timber by the heads of the nails, but also from the incrustation of rust formed by the corrosion of the iron.

A variation of this method, used in Scandinavian harbors, is the application of strips of sheet iron which seem to have a similar effect. It does not appear probable that iron strips are as efficient as nails, because the rust does not penetrate the wood so deeply.

The Corps of Engineers, U. S. A., used Dutch flat-headed nails in Douglas fir piles at San Francisco, but with only indifferent success. Details of the method are not available.

The Atchison, Topeka & Santa Fe Railway used 3d and 4d nails spaced about ½-inch in Douglas fir piles at San Diego in several wharves and trestles built between 1881 and 1883. One of these piles, pulled in 1914, was found to be intact, and 65 out of 80 examined in 1917-1918 were found to be unattacked.

The Spreckels Companies used 3d nails spaced ¼ inch for the protection of the piles in the slip of the San Diego and Coronado Ferry Company built in 1898. These piles gave about 15 years' service and failed on account of attack in checks and cracks. Considering the strains to which piles are exposed in a ferry slip this seems to be a good record.

The Santa Fe reports the cost of driving the nails to have been 10 to 13 cents per square foot of pile, and the Spreckels Company states that the school boys employed for the work protected about two linear feet of pile per day per boy.

The Charleston Dry Dock and Machine Company at Charleston, S. C., drove 600 yellow pine piles protected by roofing nails in 1918 in one of their structures located where unprotected piles last less than one year. These nails are about 1 inch in length with heads ⅜ inch to ½ inch in diameter, spaced by using ½ inch wire mesh as a template. The labor used was negro boys and the cost per linear foot of pile protected for labor and materials was about 40 cents. The piles are not only covered by an incrustation of rust but this has penetrated the wood beyond the points of the nails (Fig. 22). A number of samples were removed in 1922 which showed no attack by *Limnoria,* and while several specimens of *Bankia gouldi* were found, only one had attained any considerable size.

It would appear that this method of protection has merit, and that its cost could be much reduced from that reported by the use of machinery for driving the nails where labor costs are high, and where labor is not expensive the cost with hand labor is not excessive. Only that portion of the pile exposed to attack needs protection.

No records have been obtained of the use of hoop iron in the United States, but this method is indicated to have merit by reports received through Dr. Lorenz, Chief Engineer of the Harbor of Copenhagen, Denmark.

At Haftensund, Norway, an unprotected pile lasts from two to five years. This life is greatly increased by wrapping the piles with spirals of hoop iron spaced from 6 to 8 cm. nailed with galvanized nails spaced about 30 cm.

At Fjallbacka similar results have been obtained from the use of spirals of iron 2½ cm. wide and 3 mm. thick, spaced about four inches.

The value of this type of protection is not so thoroughly demonstrated as that by the use of nails, but it offers the great advantage that it can be applied by divers to piles already in place.

Experiments made under the direction of this Committee in tropical waters do not indicate that this method will be successful, at least where there is no period of inactivity. It does not seem probable that sheet iron strips will give as efficient protection as nails.

13. Concrete Casings

Concrete casings for timber piles may be divided into two classes, depending on the method of construction. One group would include pre-cast casings, the other casings cast in place. Casings in either group may be

constructed and placed either before or after the pile is in place in the structure.

Lock joint or other standard concrete pipe forms the earliest and cheapest form of the first group. These piles, if properly made, are stronger than vitrified clay pipe and will better resist shock from waves and drift. The space between the casing and the pile should be filled with sand or concrete. Except in still water this type of protection has not generally given satisfaction.

Casings, generally more heavily reinforced, have been manufactured for the purpose of pile protection, and give better service in proportion to their strength. One of the most promising methods recorded is that by which the Shell Oil Company saved a portion of their pier at Martinez, Cal., after it was heavily attacked by *Teredo.*

The casings, reinforced with heavy wire mesh, were built up in sections about 2 feet 6 inches in length on collapsible metal forms with a cement gun. The lowest section had a canvas gasket with steel fingers which fitted the pile sufficiently tight to retain the concrete poured into it after it was placed on the pile. The piles were cut off about 5 inches under the deck of the pier, the lower section of the casing put in place, filled with concrete, and other sections added and filled with concrete as the casing was lowered, until it rested on the mud. It was then jacked down until about 3 feet of penetration was obtained and the upper end built up under the cap by the addition of more sections filled with concrete (Fig. 23). The cost of this work is stated to have been about $2.50 per foot of pile.

The Koetitz Pile, used for new structures, consists of a reinforced concrete pre-cast casing placed over the wooden pile and driven into the bottom as soon as the pile is driven; the annular space is then filled with concrete. Ten hundred and fifty of these cylinders 26 inches in diameter with walls 3 inches thick were used in Pier 17, San Francisco, in 1910, and few of them were reported in 1922 to have shown any considerable deterioration.

There are a number of minor variations in the methods of constructing this type of protection, but the two described above may be considered typical.

There are several methods of precasting casings on piles before driving, the most recently developed of which is by the use of the cement gun, as illustrated in Tacoma, Wash., on the Municipal Piers built in 1922.

These piles were placed vertically in racks on shore; electrically welded mesh reinforcing with No. 12 wire, spaced 2 inches, was applied to the piles with chair spacers, and the gunite, in the proportion of 1 cement, 2 sand in place, was applied in two coats so as to obtain a total thickness of 2 inches. The piles after the application of the gunite were very carefully handled with locomotive cranes so as to avoid bending the piles and thus cracking the concrete. These structures are in water in which *Bankia setacea* is very active and destructive, and not far from places where the rock boring pholads are active. Frequent reports on the condition of these piles will be of very general interest.

Another type of precast casing is represented by the Ripley Pile, which has a molded casing with two layers of wire mesh reinforcing on the pile. The steamship wharf at Port au Prince, Haiti was built on these piles in 1910, and is reported to have been in good condition in 1922, although it would not appear that a detailed inspection by diver had been made.

The approach wharf to the dry dock "Dewey" at Olongapo, Philippine Islands, was constructed in 1910 on timber piles encased in cement mortar. Twelve wood furring strips one-half inch high and equally spaced were nailed to the surface of the piles, and galvanized wire cloth with ¼ inch mesh and No. 16 or No. 18 wire was fastened to the furring strips with galvanized iron staples. A cement mortar sheathing, made of 1-2 mortar, was troweled on this mesh to a minimum thickness of ½ inch over the mesh. The piles were very carefully handled and driven in a moderately firm sandy bottom.

The following table shows the amount of sheathing on the various piles:

No. of Piles	Length of each	Length of sheathed portion	Penetration of points	Penetration of sheathed portion	Unsheathed portion at butts	Unsheathed portion at points	Kinds of wood: Remarks
4	42′	22′			2′	18′	Apitong, tanguile
4	37′	17′	19	2	2′	18′	and other second
4	33′	13′	to	to	2′	18′	group timber; none
4	30′	10′	20	3	2′	18′	of which is *Teredo*
4	27′	7′	Feet	Feet	2′	18′	resisting.

It is stated that unprotected piles at this location have a useful life of from three to five years.

A report under date of April 9, 1923, gives the following information regarding the present condition of these piles:

> "1. In accordance with above reference, the Bureau is advised that the outboard rows of piles in the approach pier to the Dry Dock "Dewey," are in good condition, while the inside row is in fair condition, considering the 13 years that these piles have been in these waters.
>
> "2. The cement plaster in most cases is in very good condition, except for very fine vertical cracks about three feet long and about 4 inches apart which start at the top of the concrete above the water line within a couple of feet of the top of the timber cores. These cracks are more noticeable in the center row than in the outboard rows of piles, due to the fact that when the timber cores are wet, they have little chance to be dried out by the sun, thus becoming water logged, expanding, contracting and causing the cement plaster to crack.
>
> "3. Above the cement plaster line, the timber cores are sound, but along the cement line, the piles are rotted. By breaking the cement plaster along its bevelled edge, the timber cores show that they are rotted as deep as 3 inches all around the pile butts in the center row of piles and the rot continues down into the timber cores within the cement plaster. The same condition exists in the outboard rows of piles, except that the timber cores are rotted only in the inboard side of the piles where not accessible to the sun's rays for quick drying and that the rot in these places is only about 1½ inches deep.
>
> "4. With one exception the piles do not show any damage due to shock or impact, the piles having evidently been well prepared and carefully driven. Only row boats and small launches come alongside this pier and they do not damage these piles. One pile with broken cement plaster for a distance of about 2 feet from the top of the cement line has become very badly rotted where the cement has broken off from time to time, allowing water to settle under the broken cement plaster and causing rot to take place more quickly than in the better piles."

Fig. 22—Sections of Pile from Wharf of the Charleston Dry Dock and Machine Co., Charleston, S. C., with 4 Years' Service

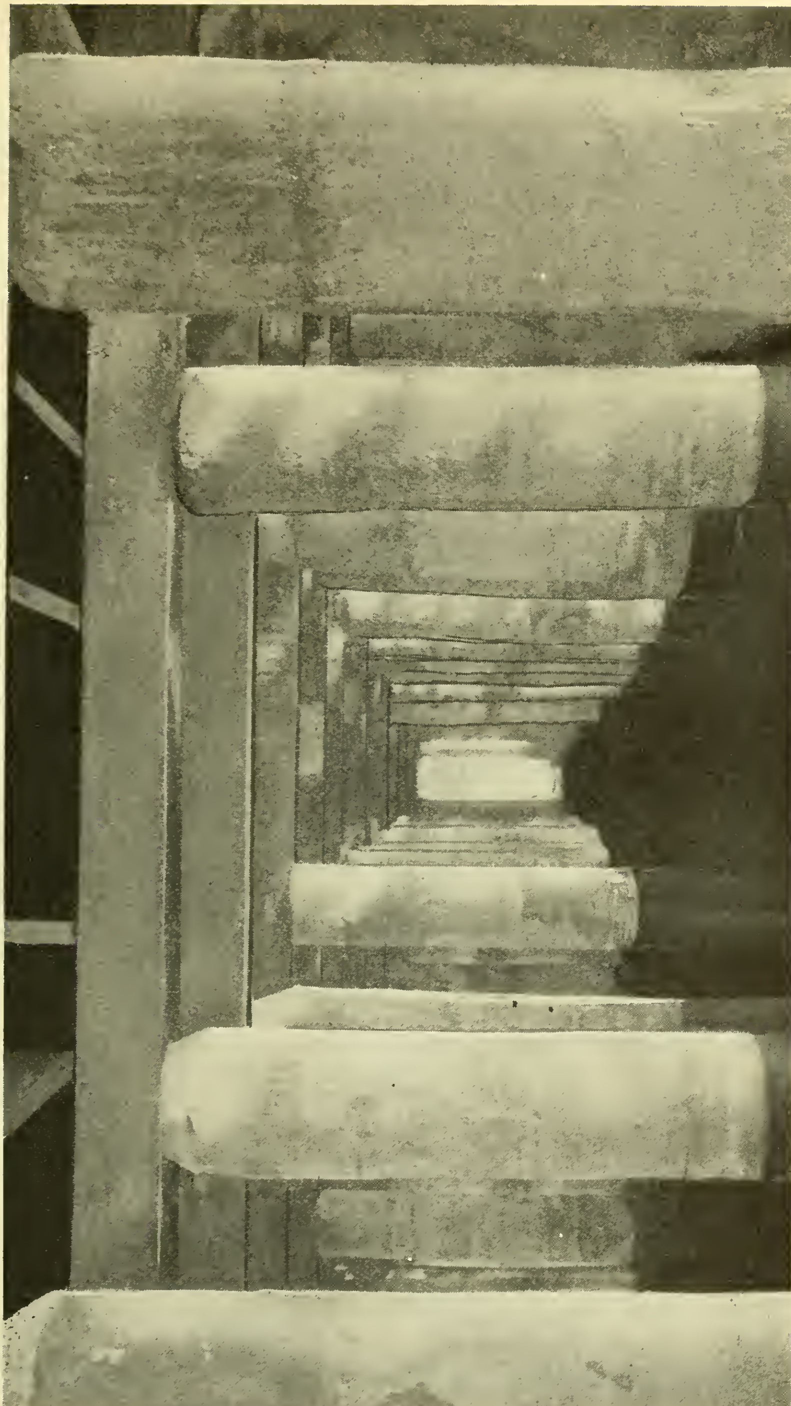


FIG. 23—GUNITE CASINGS ON SHELL OIL CO.'S WHARF, MARTINEZ, CAL.

Many methods of construction have been used for casings of this type, and the results have been quite variable, but it must be recognized that to be successful such a casing must have considerable strength to resist abrasion. This means comparatively heavy reinforcing closer to the surface than experience indicates to be wise. The concrete itself is open to the chemical attack of the sea water, and the casings are expensive, so that unless gunite is demonstrated by time to be effective it does not seem that this method of protection is one to be recommended for general use—though in special cases its use may be justified. If it is used the timber piles should be protected from decay above high water.

Concrete casings cast in place have an extremely variable record, especially in deep water; in some cases where a heavy metal form was used and left in place, fairly long life has been obtained. Casings of this type have often been employed to protect wooden piles which have been attacked by marine borers, by the use of collapsible forms which are removed after the concrete is poured. Such casings are subject to the difficulties encountered in pouring sound concrete in sea water.

The Bunker Wharf of the Spreckels Company at San Diego was built on creosoted piles in 1887, and these piles surrounded by casings poured in place. These casings have been repaired as frequently as they became broken, and the structure is still in service. This method of protection has been in quite general use in San Diego and Los Angeles.

Several piers were built in San Pedro (Los Angeles) about 1908, in which the piles were protected by casings in wooden forms left in place. When these piles were removed on account of dredging in the harbor in 1922 it was found that the forms had been attacked by borers and partially destroyed. Where the forms were gone, rock borers had attacked the concrete and thoroughly shattered it. In this destruction they were apparently aided by the disintegration of the cement by sea water. There is no information available as to the materials or methods of constructing this concrete, but the strongest piece tested after the removal of the piles showed only about 1700 pounds per square inch in compression. Some pieces inspected showed the pink color characteristic of Portland cement disintegrated in sea water. This concrete contained few coarse aggregates.

Piles wholly exposed at low tide have been protected by plastering, but with generally unsatisfactory results. An example may be found in the trestle of the Pacific Northwest Traction Company near Bellingham, Wash., where the piles were attacked by borers and were covered with a mortar coating applied in 1916. This coating was so badly broken by 1918 that it was removed and a coating applied with a cement gun, which is reported to be in good condition at present.

Several different methods of casting casings around piles and clusters of piles in place have been used in San Francisco, with the result that because of the difficulty of securing sound concrete and the cost of the processes they are not now looked upon with favor.

A typical installation of the type of protection where the forms were left in place is the repair work at the Naval Training Station at Yerba Buena Island. The piles, which were about 16 inches diameter, had been attacked by *Limnoria.* Sixteen gauge galvanized iron forms were placed around the piles and filled with concrete which was reinforced with ten gauge 4 inch wire mesh set 2 inches from the pile. This work was done in 1920 and cost about $2.00 per foot of pile protected.

The Camp Process (patented) is typical of the construction of concrete jackets with removable forms (Fig. 24). Circular wooden forms are provided with sections 3 feet in length and about $20\frac{1}{2}$ inches inside diameter, made of tongued and grooved wooden pipe staves strengthened with bands of angle iron. They are made in halves and each half is hinged in the center. When placed around the pile the halves are fastened together with tapered pins. The lower section is provided with sheet iron fingers over which canvas is fastened, and which touch the pile when the form is in place.

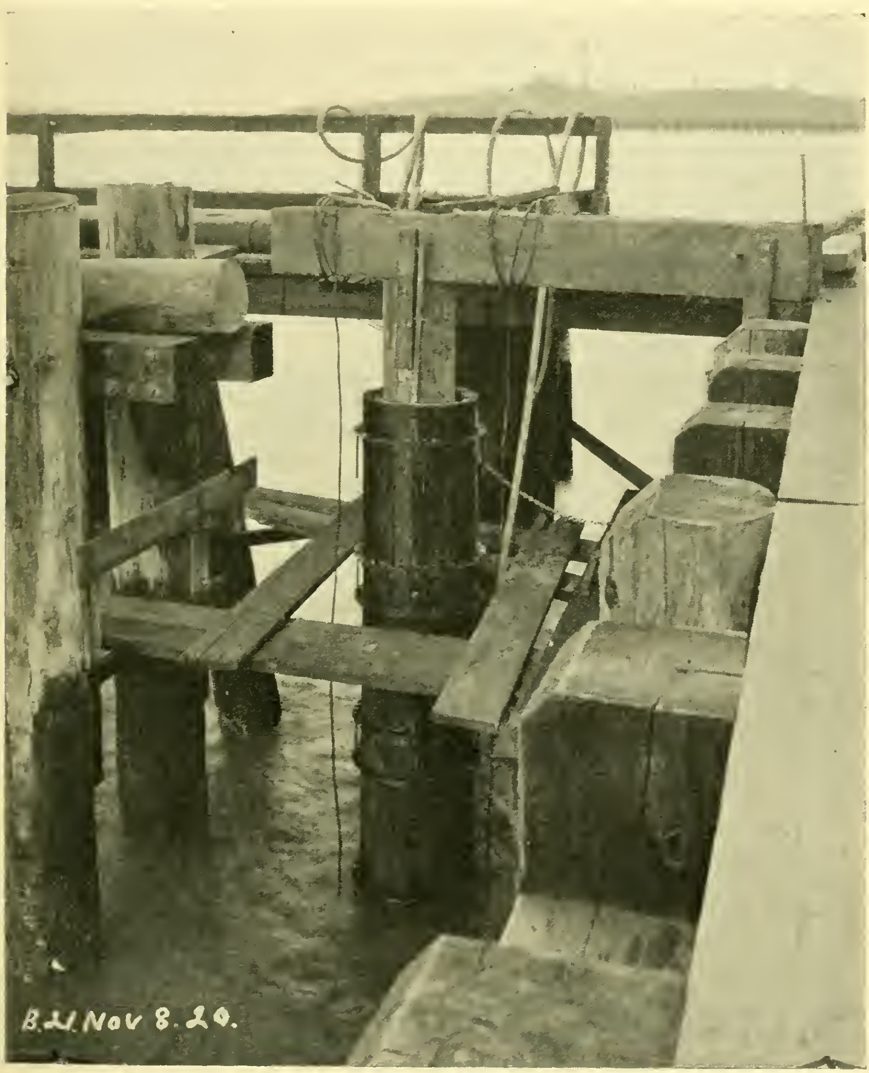


FIG. 24—FORMS IN PLACE FOR CONCRETE CASINGS CAST IN PLACE. "CAMP SYSTEM."

The process is carried out by placing the lower section around the pile, suspended by a cable on each side. This section is then filled nearly full with rather fine gravel which is held in place by the fingers and canvas. The second section is then placed and bolted to the lower one with six bolts and then filled with concrete mixed 1:2:3 soft. This process of adding sections is continued and the form lowered until it reaches the bottom. The forms are set into the mud by use of a jet or otherwise to a depth of about 3 feet. The form is left in place for about 2 days and then removed by pulling the taper pins holding the halves of the various sections together and raising them with the cables fastened to the lower section.

Even with the exercise of the greatest care it is difficult to get good concrete, especially in deep water, but the process has value in protecting piles damaged by borers without disturbing the deck of the structure. This type of protection cost in 1920 at San Francisco about $1.50 per linear foot of pile protected.

The method covered by the Holmes patent consists of driving a form 2 feet in diameter for single piles, or 3½ feet to 4 feet for clusters of 3 piles, into the bottom, sealing it, pumping out the mud and water, placing the reinforcing and filling with concrete to the bottom of the cap. The forms were made either of staves held together by round bands, or of steel plate in case of the clusters of three piles.

The service record of this type of protection for single piles is not good but is somewhat better for the larger cylinders. This method is of course for use on new structures.

One of the frequent causes of failure of concrete cased piles, or piles with other types of mechanical protection, is the erosion of the bottom and the consequent exposure of the unprotected wood to attack. Fig. 25 shows a typical example taken from the report of the Institution of Civil Engineers, 1920, where the casing was too short on both ends. If casings are used, it is absolutely necessary that the bottom of the casing be not only below the mudline but far enough below so that there is no chance that scour will uncover unprotected timber, and the top should be above high water.

VI. INJECTED PRESERVATIVES

1. Soluble Salts

Soluble salts, while they may be very poisonous to animal life, will give protection to a pile only so long as the dissolving and chemical effect of sea water does not reduce their concentration below the lethal toxicity required. The following materials and methods have been tried in the United States or abroad with generally unsatisfactory results:

- Copper sulphate
- Paynizing
- Gerlaches solution
- Acetate of lead
- Kyanizing
- Thilmany process
- Sulphate of iron
- Soluble glass and chloride of calcium

Test blocks injected with arsenious iodide and copper iodide with a paraffine carrier, a process patented by Dr. Paul Bartsch, are under test by the Forest Products Laboratory at Pensacola, Fla. Specimens were installed January, 1923, together with untreated specimens and specimens treated with paraffine alone. When inspected one year later, in January,

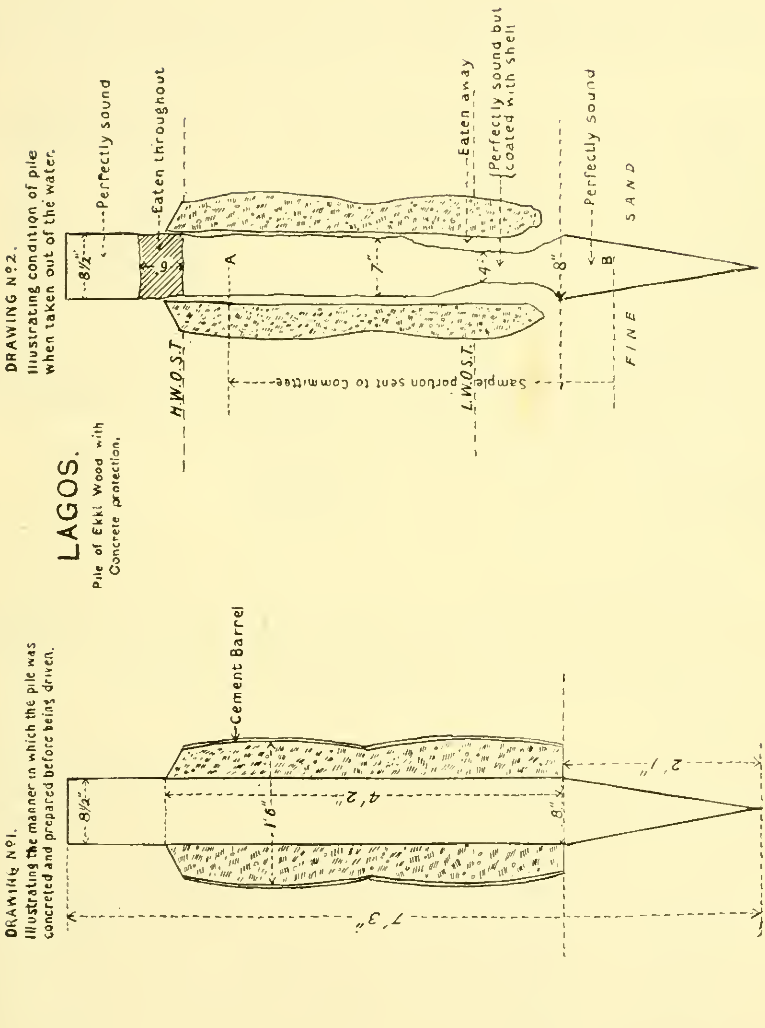


Fig. 25.—Sketch Showing Result of Building Casings too Short.
(Reproduced from 1st Report, Inst. of Civil Engineers)

1924, the untreated specimens were found to be completely destroyed, and the treated specimens were all attacked by shipworms. It is probable that in another year the treated specimens will be destroyed. Specimens treated with paraffine alone appeared to resist attack to about the same degree as those treated with paraffine and the copper and arsenious salts. Tests of similar specimens by the San Francisco Committee gave similar results, except that the arsenious salts seemed to resist better than the others.

The process of double injection, that is, locking the soluble compound in the timber with one that is insoluble, by precipitation or otherwise, is a promising field for experiment. One of the dangers is that this method will be so expensive as to be uneconomical. Several of these processes are:

PROCESS	FIRST INJECTION—SOLUTION OF:	SECOND INJECTION—SOLUTION OF:
Jacques	Soap	Tar acids
Richards	Common salt	Alum
Muller	Phosphate of soda	Chloride of barium
Hattzfeld	Tannin	Acetate of iron
Krug	Soda	Creosote
Wellhouse	Chloride of zinc and glue	Tannin

2. Wood Products

Various wood products have been tried and generally found wanting. Records of 24 tests, none of which were successful, are available, covering the following substances said to be wood products:

Wood creosote	Spiritine
Ferneline	Pinoline
Wood distillate	Resin oil
Resin	

3. Creo-Resinate Process

Two tests of wood preserved by this process were reported by the Forest Products Laboratory; one in Virginia showed "badly attacked by shipworm in 7 years," and the other in Texas "riddled in less than 2 years."

4. Powellizing

The Powellizing process, which is patented, consists of first immersing the timber in a thin syrup of raw sugar or other saccharine matter, which is heated to the boiling point and maintained at that temperature for several hours. Other ingredients, some of them toxic, are sometimes added to the syrup. After the boiling process has been completed, the liquor is allowed to cool to 100° Fahr. or less, and then drawn off. The timber is then subjected to a process of artificial drying, which is effected by gradually raising the temperature in the drying chamber to about 170° Fahr., the humidity being reduced from 85 per cent or 90 per cent to 35 per cent.

The report of the Institution of Civil Engineers, 1920, indicated that while this process extended the life of the timber in borer infested waters, it did not give immunity from attack.

5. Creosote Impregnation

Impregnation of timber with creosote is one of the best methods in general use for the protection of timber against decay, and it has been also recog-

nized as a generally efficient protection against marine borers for a number of years. The value of creosote seems to be less in warm waters than in colder ones, and some creosotes seem more efficient than others. It is not known whether the effectiveness of creosote depends on its toxicity, or whether it acts as an inhibitant preventing the larvae of the molluscan and the young of the crustacean borers from landing on the wood.

The cause of the failure of some creosoted timber is undoubtedly the leaching of the creosote from the wood by sea water, or the absence of the necessary protective constituent. Much study has been given to these subjects, and many experiments have been made or are under way, in an endeavor to find the reasons for success or failure.

Naturally the first investigations dealt with examinations of creosotes extracted from old piles, both from such as were still perfectly sound, and from those partly or wholly destroyed by various marine borers. For the sake of ready reference a number of these older investigations follow herewith, together with brief conclusions developed by the various investigations.

When the Long Wharf of the Southern Pacific Railway at Oakland, Cal., was removed in 1918-1919, after the piles had been in service from 18 to 29 years, several pile sections were analyzed with the following results, which are taken from the proceedings of the American Wood Preservers Association, 1920, pages 157-158. Sections cut from that portion of each pile in air, in water, and in mud, were analyzed by Mr. Mattos of the Southern Pacific Company.

ANALYSES OF CREOSOTE OIL EXTRACTED FROM PILE NO. 27 REMOVED FROM DOCK A AFTER 29 YEARS OF SERVICE

	AIR	WATER	MUD
Radius of section	7.5 in.	7.25 in.	6.5 in.
Radius of untreated portion of section	6.5 in.	6.25 in.	5.5 in.
Percentage of oil in treated ring	40.68	54.75	47.49
Pounds of oil per cubic foot of treated wood	13.02 lbs.	17.52 lbs.	15.19 lbs.
Pounds of oil per cubic foot based on the area of the entire cross section	3.24 lbs.	4.45 lbs.	4.31 lbs.
Specific gravity of extracted oil at 38° C.	1.059	1.044	1.0436
Specific gravity of fraction 235° C. to 315° C. at 38° C.	1.0365	1.0488	1.0422
Specific gravity of fraction 315° C. to 355° C. at 38° C.	1.0934	1.0920	1.0798
Tar acids	0.6%	0.2%	0.7%

FRACTIONS

RANGE	AIR	WATER	MUD
0 to 170° C.	0.16%	0.68%	0.15%
170 to 200° C.	0.53%	1.84%	1.25%
200 to 210° C.	2.57%	2.48%	1.95%
210 to 235° C.	30.06%	49.00%	37.60%
235 to 270° C.	25.70%	19.40%	23.25%
270 to 315° C.	9.60%	7.75%	7.05%
315 to 355° C.	13.40%	10.75%	12.70%
Residue above 355° C.	17.98%	8.10%	16.05%
	100.00%	100.00%	100.00%

NOTE—Residue soft in each case.

Analyses of Creosote Oil Extracted from Pile No. 3 Removed from Dock A after 29 Years of Service

	Air	Water	Mud
Radius of section	6.25 in.	5.88 in.	5.40 in.
Radius of untreated portion of section	4.30 in.	4.25 in.	3.88 in.
Percentage of creosote in treated ring	48.59	57.21	64.73
Pounds of creosote per cu. ft. of treated wood	15.55 lbs.	18.31 lbs.	20.71 lbs.
Pounds of creosote per cubic foot based on area of entire cross-section	8.19	9.97	10.04
Specific gravity of extracted creosote at 38° C.	1.0898	1.07	1.0796
Specific gravity of fraction 235° C. to 315° C. at 38° C.	1.0477	1.0414	1.0550
Specific gravity of fraction 315° C. to 355° C. at 38° C.	1.113	1.1248	1.1270
Tar acids	3.1%	1.8%	3.3%

Fractions

Range	Air	Water	Mud
0° C. to 200° C.	0.00%	0.00%	0.00%
200° C. to 210° C.	0.00%	1.00%	1.45%
210° C. to 235° C.	5.25%	3.10%	6.10%
235° C. to 270° C.	15.25%	17.40%	24.45%
270° C. to 315° C.	19.95%	26.50%	20.45%
315° C. to 355° C.	28.55%	27.60%	26.25%
Residue above 355° C.	31.00%	24.40%	21.30%

Note—Residue soft in each case.

Analyses of Creosote Oil Extracted from Pile Removed from Dock C After 22 Years of Service

	Air	Water	Mud
Radius of section	7.37 in.	6.75 in.	6.75 in.
Radius of untreated portion of section	6.37 in.	5.87 in.	5.87 in.
Percentage of creosote in treated ring	39.97	40.98	51.50
Pounds of creosote per cu. ft. of treated wood	12.79	13.11	16.48
Pounds of creosote per cubic foot, based on area of entire cross section	3.23	3.18	4.00
Specific gravity of creosote extracted at 38° C.	1.078	1.0644	1.0682
Specific gravity of fraction 235° C. to 315° C. at 38° C.	1.0373	1.0265	1.0261
Specific gravity of fraction 315° C. to 355° C. at 38° C.	1.0634	1.0703	1.0737
Tar acids	5.49%	4.14%	6.00%

Fractions

Range	Air	Water	Mud
0° C. to 210° C.	0.00%	0.00%	0.00%
210° C. to 235° C.	0.00%	1.84%	6.86%
235° C. to 270° C.	14.86%	22.12%	21.76%
270° C. to 315° C.	31.06%	25.07%	24.46%
315° C. to 355° C.	26.47%	25.11%	22.55%
Residue above 355° C.	27.61%	25.86%	24.37%

Note—The residue above 355° C. in the case of the air section was hard and brittle, while in the water and mud sections the residue, although hard, was more elastic than the residue of creosote extracted from the air section.

Analyses of Creosote Oil Extracted from Pile Removed from Dock D After 20 Years of Service

	Air	Water	Mud
Radius of section	7.0 in.	6.50 in.	5.37 in.
Radius of untreated portion of section	6.0 in.	5.62 in.	4.37 in.
Percentage of creosote in treated ring	45.0	47.06	54.8
Pounds of creosote per cubic foot of treated wood	12.4	15.06	17.53
Pounds of creosote per cubic foot, based on area of entire cross section	3.82	3.78	5.91
Specific gravity of creosote extracted at 38° C	1.0758	1.0613	1.0562
Specific gravity of fraction 235° C. to 315° C. at 38° C	1.0210	1.0212	1.0244
Specific gravity of fraction 315° C. to 355° C. at 38° C	1.0638	1.0756	1.0810
Tar acids	5.0%	3.4%	6.3%

Fractions

Range	Air	Water	Mud
0° C. to 170° C	0.00%	0.00%	0.00%
170° C. to 200° C	0.00%	0.00%	1.10%
200° C. to 210° C	0.00%	0.95%	2.65%
210° C. to 235° C	1.20%	3.10%	12.30%
235° C. to 270° C	7.95%	24.70%	22.40%
270° C. to 315° C	28.25%	24.45%	21.25%
315° C. to 355° C	26.85%	22.75%	21.95%
Residue above 355° C	35.75%	24.05%	18.35%

Note.—The residue of creosote extracted from air section above 355° C. was hard, but not brittle upon cooling. In case of the water and mud sections, the residue above 355° C. was soft.

Analyses of Creosote Oil Extracted from Pile Removed from Dock E After 18 Years of Service

	Air	Water	Mud
Radius of section	7.0 in.	6.37 in.	5.0 in.
Radius of untreated portion of section	6.0 in.	5.37 in.	4.0 in.
Percentage of creosote in treated ring	39.67	48.77	50.00
Pounds of creosote per cubic foot of treated wood	12.69	15.60	16.00
Pounds of creosote per cubic foot, based on area of entire cross section	3.36	4.51	5.76
Specific gravity of extracted creosote at 38° C	1.0562	1.0412	1.0386
Specific gravity of fraction 235° C. to 315° C. at 38° C	1.0210	1.0163	1.0142
Specific gravity of fraction 315° C. to 355° C. at 38° C	1.0836	1.0752	1.0763
Tar acids	2.85%	3.5%	3.5%

FRACTIONS

RANGE	AIR	WATER	MUD
0° C. to 170° C.	0.00%	0.00%	0.00%
170° C. to 200° C.	1.45%	1.05%	2.25%
200° C. to 210° C.	1.30%	1.25%	1.20%
210° C. to 235° C.	12.65%	12.85%	8.00%
235° C. to 270° C.	25.25%	30.95%	30.10%
270° C. to 315° C.	19.70%	19.55%	19.80%
315° C. to 355° C.	22.10%	19.45%	20.25%
Residue above 355° C.	17.55%	14.90%	14.40%

NOTE.—The residue above 355° C. in the case of creosote extracted from the air section upon cooling was hard and brittle, while in the case of the creosote extracted from the water and mud line sections the residue above 355° C. was soft.

The piles in this structure driven in 1890 and 1892, about 7 per cent of the total, were treated with English creosote by the Bethell process at the Southern Pacific plant at San Pedro, Cal., in 1889. They had an average absorption of 14.17 pounds per cubic foot. The remaining 93 per cent of the piles, about 13,000 in number, were treated with English creosote at the Southern Pacific plant at West Oakland, Cal., by the boiling process patented by John D. Isaacs and W. G. Curtis in 1895. Their average absorption was about 10 pounds per cubic foot.

A careful inspection was made of 4098 of these piles, and from 23 per cent to 37 per cent of those examined in the various structures were found to have been attacked by shipworms and *Limnoria lignorum*, generally in knots or through injuries from abrasion, punctures, etc.

At the time these piles were examined a hole filled with creosote was found in one of the sections cut below the mud line from Pile No. 1, Dock A, treated in 1890. It is thought that the chances of changes having occurred in this creosote are small and that it may fairly be considered to be representative of the original creosote. The analysis of this sample, which was made by von Schrenk and Kammerer, St. Louis, Mo. (A. R. E. A. Transactions, 1922, Vol. 23, p. 974) follows:

Specific gravity at 38° C.		1.079
Water		1.0%
Distillation—		
210° C.	0.8%	
235° C.	13.4%	
270° C.	20.4%	
315° C.	17.9%	
355° C.	28.0%	
Residue	19.5%	
Specific gravity 38/15.5° of 235-315 fraction		1.045
Specific gravity 38/15.5° of 315-355 fraction		1.122
Acids by volume		2.8%

Analysis of creosote extracted from this pile will be found on page 115.

Similar analyses were made of other piles in the laboratories of the Atchison, Topeka and Santa Fe Railroad. Three sections were cut from four piles as was done for the Southern Pacific analyses, but in addition to the analysis careful measurements were made of the impregnated portion of each pile. The following tables show the results of these measurements and analyses.

PHYSICAL MEASUREMENT AND DATA FROM LOGS

Specimen	Diameter of Log			Total area sq. in.	Depth of penetration in inches		Percentage of Creosote area to area of entire log
	Maximum	Minimum	Average		Maximum	Minimum	
Air							
3 Side A	14.09	12.56	13.33	139.25	4.13	1.81	69.2
3 Side B	13.47	12.38	12.93	132.56	3.56	2.06	69.7
Average	13.78	12.47	13.13	135.90	3.85	1.94	69.5
Water							
3 Side A	12.25	11.38	11.82	110.10	4.75	1.94	72.5
3 Side B	12.50	11.50	12.00	112.50	3.88	1.50	64.9
Average	12.38	11.44	11.91	111.30	4.32	1.72	68.7
Mud							
3 Side A	11.19	10.47	10.83	95.96	3.94	1.56	71.6
3 Side B	11.44	10.56	11.00	96.20	4.75	2.63	86.2
Average	11.32	10.52	10.92	96.08	4.35	2.10	78.9
Air							
10 Side A	11.88	10.88	11.38	103.36	5.66	0.41	81.6
10 Side B	11.81	10.97	11.39	102.91	5.64	0.38	61.4
Average	11.85	10.93	11.39	103.14	5.65	0.40	71.5
Water							
10 Side A	11.44	10.38	10.91	96.31	8.25	0.28	61.4
10 Side B	11.25	10.50	10.88	94.56	1.94	0.34	29.3
Average	11.35	10.44	10.89	95.44	5.10	0.31	45.4
Mud							
10 Side A	9.94	8.94	9.44	70.95	6.75	0.28	59.9
10 Side B	10.03	9.13	9.58	72.93	2.78	0.34	40.9
Average	9.99	9.04	9.51	71.94	4.77	0.31	50.4
Air							
14 Side A	16.07	13.88	14.98	167.09	4.94	1.34	69.5
14 Side B	15.97	14.00	14.99	174.16	9.75	1.00	77.9
Average	16.02	13.94	14.99	170.63	7.35	1.17	73.7
Water							
14 Side A	14.00	13.32	13.66	145.38	3.38	0.81	49.2
14 Side B	13.88	13.00	13.44	141.47	3.94	1.22	57.1
Average	13.94	13.16	13.55	143.43	3.66	1.02	53.2
Mud							
14 Side A	12.06	11.25	11.65	109.80	2.94	0.81	46.7
14 Side B	12.13	11.25	11.69	108.25	2.66	0.63	47.9
Average	12.10	11.25	11.67	109.02	2.80	0.72	47.3
Air							
37 Side A	15.00	14.13	14.57	167.25	3.50	1.50	50.4
37 Side B	15.81	14.16	14.99	169.03	4.00	1.53	48.9
Average	15.41	14.15	14.78	168.14	3.75	1.52	49.7
Water							
37 Side A	14.34	13.78	14.06	158.68	3.28	1.25	45.2
37 Side B	14.50	13.69	14.10	159.46	2.13	0.75	39.8
Average	14.42	13.74	14.08	159.07	2.71	1.00	42.5
Mud							
37 Side A	12.63	12.00	12.32	119.36	1.94	1.31	44.0
37 Side B	12.56	12.19	12.38	121.00	3.19	1.38	53.9
Average	12.60	12.10	12.35	124.68	2.57	1.35	49.0

ANALYTICAL DATA

	Log 3 Air	Log 3 Water	Log 3 Mud	Log 14 Air	Log 14 Water	Log 14 Mud	Log 37 Air	Log 37 Water	Log 37 Mud	Log 10 Air	Log 10 Water	Log 10 Mud
Moisture in log as received, per cent	10.00	16.35	12.43	10.03	19.81	11.62	13.84	15.81	15.93	7.56	17.87	17.95
Specific gravity of creosote, 38°/15.5° C.	1.096	1.090	1.087	1.105	1.101	1.090	1.098	1.101	1.105	1.045	1.045	1.046
Creosote in log, lb. per cu. ft.	8.48	8.22	8.59	7.48	6.90	9.47	6.91	6.30	6.87	4.07	4.35	4.75
Tar acids	2.14	1.76	1.43	1.40	1.40	1.20	1.50	1.80	1.50	2.40	3.00	1.70
Fractions:												
0-170° C.	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
170-200° C.	1.14	1.51	1.60	0.96	0.00	1.21	1.95	3.30	0.00	5.50	3.20	1.86
200-210° C.	1.76	1.45	1.08	0.58	0.00	1.48	1.17	1.47	0.00	4.64	4.18	3.07
0-210° C.	2.90	2.96	2.74	1.54	0.00	2.69	3.12	4.77	0.00	10.14	7.38	4.93
210-235° C.	6.74	6.74	6.41	3.02	4.27	8.53	4.46	5.91	0.52	33.32	27.15	35.85
0-235° C.	9.64	9.70	9.15	4.56	4.27	11.22	7.58	10.68	0.52	43.46	34.53	40.78
235-270° C.	13.32	20.25	20.03	15.62	23.32	21.11	13.94	16.00	21.39	15.86	17.73	19.11
270-315° C.	21.55	20.40	19.48	23.46	21.01	18.47	22.08	19.74	23.74	10.18	10.13	10.15
315-355° C.	30.18	28.32	30.15	29.84	27.44	28.35	29.27	29.48	29.10	16.91	25.61	16.78
Residue	25.31	21.33	21.19	26.52	23.96	20.85	27.13	24.10	25.25	13.59	12.00	13.18
Above 315° C.	55.49	49.65	51.34	56.36	51.40	49.20	56.40	53.58	54.35	30.50	37.61	29.96
Specific gravity of 210-235 fraction	....	....	....	....	....	....	....	....	....	1.008	1.013	1.014
Specific gravity of 235-315 fraction	1.046	1.044	1.048	1.044	1.044	1.046	1.044	1.041	1.046	1.032	1.036	1.035
Specific gravity of 315-355 fraction	1.108	1.111	1.111	1.111	1.108	1.109	1.110	1.110	1.111	1.064	1.050	1.075

Analyses of four other piles from the Long Wharf made by von Schrenk and Kammerer, St. Louis, are reported in the Proceedings of the American Railway Engineering Association, Vol. 23 (1922) page 973, as follows:

PILES FROM DOCK A, SOUTHERN PACIFIC CO., CREOSOTED 1890

Pile Number	1			4		
Mark Exposure	1-2 Air	1-4 Water	1-7 Mud	4-1 Air	4-4 Water	4-8 Mud
% Creosote in treated part	43.97	43.17	58.24	38.16	37.93	39.82
% Moisture	11.64	38.53	26.61	14.0	28.6	19.81
Sp. Gr. at 38° C	1.093	1.086	1.085	1.047	1.042	1.044
200° C	0.0%	0.0%	0.5%	0.7%	0.4%	0.4%
210° C	1.0	0.3	0.1	0.9	0.9	0.4
235° C	3.5	2.9	4.2	48.0	43.6	50.6
270° C	13.9	22.0	22.7	16.3	21.5	13.8
315° C	21.7	18.3	19.0	8.2	8.7	10.2
355° C	32.9	32.0	29.5	12.7	13.9	13.2
Residue	27.0	24.5	24.0	13.2	11.0	11.4
Sp. Gr. at 38°/15.5° C						
235-315	1.044	1.037	1.036	1.048	1.029	1.033
315-355	1.112	1.107	1.110	1.105	1.110	1.107
Tar acids by volume	4.0%	3.2%	2.5%	1.5%	1.3%	....

Pile Number	23			37		
Mark Exposure	23-2 Air	23-2 Water	23-6 Mud	37-1 Air	37-5 Water	37-10 Mud
% Creosote in treated part	26.57	28.59	61.36	57.91	49.39	55.65
% Moisture	20.96	32.30	34.39	13.78	32.52	25.90
Sp. Gr. at 38° C	1.056	1.042	1.041	1.093	1.084	1.083
200° C	0.7%	0.5%	0.4%	1.2%	0.5%	0.3%
210° C	1.9	0.7	0.8	0.2	0.1	0.7
235° C	38.8	48.4	53.0	4.0	3.5	5.4
270° C	17.7	18.3	18.3	21.6	22.1	23.3
315° C	9.4	6.9	8.6	18.2	22.0	22.5
355° C	16.5	13.0	10.3	31.5	31.1	26.0
Residue	15.0	12.2	9.0	23.3	20.7	21.3
Sp. Gr. at 38°/15.5° C						
235-315	1.034	1.034	1.038	1.039	1.038	1.039
315-355	1.106	1.110	1.114	1.125	1.114	1.118
Tar Acids by volume	1.2%	....	....	1.2%	1.3%	1.7%

A paper presented by Mr. F. B. Ridgway before the American Wood Preservers' Association (Proceedings A. W. P. A., 1914, page 194) describes the material used in two trestles built by the Atchison, Topeka and Santa Fe Railroad across Galveston Bay, Tex., and the following information is abstracted from this paper.

The original structure was built in 1875 on creosoted piling. In 1895 this trestle was rebuilt, again using creosoted piling and leaving many of the 1875 piles in place. This trestle was dismantled in 1912 and the piles pulled.

The piles used in the 1895 structure, 3107 in number, were all long leaf yellow pine with the exception of 110 which were red cedar. The pine piles were steamed for 24 hours at a pressure of about 55 pounds, and 12 hours

additional at from 47 to 50 pounds. A vacuum was then maintained for 4 hours and then creosote injected until an absorption of 24 pounds per cubic foot was obtained.

A careful inspection made in 1905 showed no serious damage to the piles by marine borers, and it was estimated, when the structure was removed in 1912, that not over 10 per cent were seriously enough damaged to make them unfit for further use.

No analysis was made of the creosote used in 1895, but it was an English product, and analyses of the creosote extracted from sections cut below the mud line indicate that it was low boiling and very rich in solids, especially naphthalene.

The analysis of the creosote extracted from the sections cut below the mud line from the 1875 and 1895 piles was as follows:

Mud Sections
1895 Piles (3 and 4)

To 170° C.	None	
170° C.-200° C.	1.3%	Semi-solid
200° C.-210° C.	3.8%	Solid
210° C.-235° C.	44.4%	Solid
235° C.-270° C.	18.0%	Semi-solid
270° C.-315° C.	11.6%	Liquid (some solid)
315° C.-355° C.	9.1%	Solid
Residue	11.6%	
	99.8%	

Mud Sections
1875 Piles (1 and 2)

To 170° C.	None	
170° C.-200° C.	.5%	Semi-solid
200° C.-210° C.	1.1%	Solid
210° C.-235° C.	21.4%	Solid
235° C.-270° C.	26.2%	Solid
270° C.-315° C.	17.6%	Liquid (some solid)
315° C.-355° C.	14.3%	Solid
Residue	18.9%	
	100.0%	

"Out of an unknown number of yellow pine piling creosoted in 1875, exact amount of injection (chiefly a light treatment) unknown, and exact process of seasoning, also unknown, after 38 years' standing in Galveston Bay, some few still in sound condition, but the majority very badly attacked by *Limnoria* and *Teredo* and a great number almost completely eaten away from mud line to water line.

"Out of about 3,000 creosoted yellow pine piling, strictly long leaf, creasoted in 1895, with a low distilling creosote oil, containing approximately 60 per cent of naphthalene and between 12 and 15 per cent of "tar acids," an oil which would be excluded by practically all of the widely used present-day specifications in this country, seasoned by heavy steaming (probably by many considered excessive), injection of oil 24 pounds per cubic foot of wood, have stood in Galveston Bay under heavy traffic for 18 years and over 90 per cent still good."

Analyses of other piles from these structures were reported in Forest Service Circular 98 (1908) as follows:

ANALYSES AFTER EXPOSURE OF CREOSOTE USED IN 1875

Sample	Source	Species	Service	Creosote Per Cubic Foot	DISTILLATION OF EXTRACTED OIL							Solid Naphthalene from Distillates	Solid Anthracene Oil from Distillates
					To 205° C.	205° C. to 245° C.	245° C. to 270° C.	270° C. to 320° C.	320° C. to 420° C.	Residue	Total		
			Years	Pounds	%	%	%	%	%	%	%		
Pile No. 50	Inter. Creo. & Construc. Co.	Loblolly Pine	29	17.63	1.26	27.60	22.43	31.22	12.02	5.13	99.66	25.41	48.15
Pile No. 51	Inter. Creo. & Construc. Co.	Loblolly Pine	29	17.08	2.18	31.06	18.21	36.04	8.17	4.13	99.79	28.10	41.12

Analyses of Creosotes from Galveston Bay Bridge Piling

Analysis No.	Description of Sample Used for Analysis	Amount Oil per Cu. Ft. Extracted	Est. treatment whole pile	Treatment given charge material	Distillation of Extracted Oil: To 205°	205° to 245°	245° to 270°	270° to 320°	Residue Above 320°	Total	Tar Acids Below 320°	Sulphonation Residue Below 320° C.	Condition of distillates at 20° C.
No.		Lbs.	Lbs.	Lbs.	%	%	%	%	%	%	C. C.	C. C.	
1	Air Sec. No. 1 1875 Sound Pile	5.10	13.2	Unkn.	None	20.4	11.3	26.7	41.6	100	8.5	1.2	2 semi solid, 3 and 4 liquid (some crystals)
2	Water Sec. No. 1 1875 Sound Pile	6.12	13.2	Unkn.	None	23.3	18.6	21.2	36.4	99.5	5.0	1.4	2 semi solid, 3 and 4 liquid (some crystals)
3	Mud Sec. No. 1 1875 Sound Pile	9.25	13.2	Unkn.	1.1	36.7	14.4	19.7	27.7	99.6	10.0	1.1	1 and 2 semi solid, 3 and 4 liquid (some crystals)
4	Air Sec. No. 2 1875 Badly Attck. Pile	6.49	14.3	Unkn.	None	16.8	13.0	20.4	49.8	100	8.2	1.1	2 semi solid, 3 and 4 liquid (some crystals)
5	Mud Sec. No. 2 1875 Badly Attck. Pile	10.05	14.3	Unkn.	1.5	38.0	12.4	19.3	28.3	99.5	....	1.1	1 and 2 semi solid, 3 and 4 liquid (some crystals)
6	Air Sec. No. 3 1895 Sound Pile	9.71	15.1	24	2.2	55.5	8.2	12.3	21.6	99.8	10.3	.8	1 and 2 solid, 3 and 4 semi solid
7	Water Sec. No. 3 1895 Sound Pile	9.14	15.1	24	1.3	58.5	9.5	12.5	18.2	100	5.5	.8	1 and 2 solid, 3 and 4 semi solid
8	Mud Sec. No. 3 Sound Pile	10.60	15.1	24	3.3	56.6	9.7	12.1	17.8	99.5	11.7	.8	1 and 2 solid, 3 and 4 semi solid
9	Air Sec. No. 4 1895 Badly Attck. Pile	4.38	13.3	24	Trace	48.4	10.1	13.7	27.8	100	9.1	.7	2 solid, 3 and 4 semi solid
10	Water Sec. No. 4 1895 Attk. by Limnoria	6.38	13.3	24	1.0	51.7	10.8	15.2	21.0	99.7	5.2	.8	1 and 2 solid, 3 and 4 semi solid
11	Mud Sec. No. 4 1895 Attk. by Limnoria	9.28	13.3	24	3.2	57.9	9.8	10.8	18.2	99.9	11.8	.8	1 and 2 solid, 3 and 4 semi solid
12	Water Sec. No. 5 1895 Attk, by Teredo	4.86	(a) 11.4	24	.3	37.8	11.8	14.3	35.5	99.7	....	....	1 and 2 solid, 3 and 4 semi solid
13	Water Sec. No. 6 1895 Sound Pile	8.83	22.5	24	(b)	49.9	8.8	13.6	27.5	99.8	....	....	2 solid, 3 and 4 semi solid
14	Mud Sec. No. 6 1895 Sound Pile	15.72	22.5	24	5.5	54.9	8.1	11.0	20.4	99.9	....	....	1 and 2 solid, 3 and 4 semi solid
15	Water Sec. 1895 Sound Cedar Pile	3.22	....	Unkn.	Trace	44.1	23.9	17.5	14.1	99.6	6.1	....	2 chiefly solid (some liquid) 3 & 4 semi solid
16	Mud Sec. No. 7 1895 Sound Pile	14.36	20.5	24	3.1	58.4	9.7	12.4	16.4	100	10.0	.8	2 solid, 1, 3 and 4 semi solid
17	Mud Sec. No. 8 1895 Sound Pile	14.16	20.2	24	4.6	62.2	8.8	10.5	13.8	99.9	13.6	.7	1 and 2 solid, 3 and 4 semi solid

(a) Estimated from water section assuming 40% evaporation.
(b) Through error—No observation made at 205° C.

Another report on piles of long service is presented by Mr. Ernest Bateman in Forest Service Circular 199, 1912. The two piles examined were treated by the Bethell Process, but nothing was known as to the source of the creosote or the amount injected.

Description of Specimens

Pile No. 1.—This pile, said to have been in service 30 years, was perfectly preserved, showing no indications of decay nor of attack by *Teredo.* The portion above water was badly checked. It was received in three sections: Section 1, taken from above the water line; section 2, taken from near the mud line; section 3, taken from the lower end of the pile in the mud.

Pile No. 2.—This pile, which had been creosoted and placed in the Biloxi Bay trestle in 1879, and removed in July, 1910, had been attacked by *Teredo,* especially near the water line. Only a portion of the whole pile, approximately 6 feet long, extending 3 feet above and 3 feet below the water line, was received. This will be considered as three sections: Section 1, above the water line; section 2, at the water line; section 3, below the water line.

Examination for the Quantity of Creosote Present

Samples from the several portions of the piles were taken by borings distributed over the entire cross section. A weighed portion of the average samples from each section thus obtained was treated with chloroform; and the loss in weight after treatment and drying was determined. The loss includes all the creosote, all the rosin, and all the moisture. The extracted material was then treated with a sodium carbonate solution, and the dissolved rosin was recovered by precipitating it with acid. Moisture determinations were made on separate portions of the original sample. Then the amount of rosin and moisture was subtracted from the total of creosote, rosin and water. The result was calculated in pounds of creosote per cubic foot of wood. Measurements of the relative proportions of the treated and untreated area of each cross section were then made. From these measurements and the previous calculations, estimates were made of the quantity of creosote in the treated portion only. The results obtained are given in Table 1.

Table 1. Quantity of Creosote in Two Piles

Pile No.	Section No.	Amount of Creosote Found per Cubic Foot: Entire Cross Section. Pounds	Amount of Creosote Found per Cubic Foot: Treated Portion Only. Pounds
1	1	2.6	4.5
1	2	10.7	15.3
1	3	12.0	17.1
2	1	10.4	17 0
2	2	5.8	16.5
2	3	11.5	17.9

In the case of pile No. 2 the amount of creosote in the entire cross section at the water line (sec. 2) is only about half of that in either of the other two sections; but when calculated for the treated portion only it is nearly the same. This difference is due to the loss of a great portion of the creosoted wood in this section, making the proportion of untreated to treated wood much higher than in the other two cases. The proportion of the treated area in the three sections of this pile as received at the laboratory was: Section 1, 61 per cent treated; section 2, 35 per cent treated; section 3, 64 per cent treated.

Analysis of Extracted Oils

To determine the quality of the creosote, the oil was extracted from a large volume of chips by chloroform. The resulting extract was then freed from rosin by the use of sodium carbonate, and from chloroform by distillation. The residual creosote was then analyzed according to the method described in Forest Service Circulars 112 and 191. The results of these analyses are given in Tables 2 and 3.

Table 2—Results of Fractional Distillation and Index of Refraction Determinations of Creosote Extracted from Pile No. 1

Temperature	Percentage weight of distillate			Average index of refraction of 2 and 3
	Section 1	Section 2	Section 3	
° C.				
205		....	2.5	......
215	2.0	2.7	2.0	......
225		15.5	26.3	......
235	8.2	12.0	8.5	1.5922
245		3.1	2.5	1.5920
255	13.7	2.1	2.0	1.5921
265		2.6	1.9	1.5939
275	6.6	2.4	2.5	1.5981
285	5.0	3.2	3.3	1.6041
295	6.2	4.1	3.5	1.6123
305	6.0	4.8	4.3	1.6203
320	10.5	8.6	7.9	1.6310
Residue	41.6	38.4	32.3	......

Table 3—Results of Fractional Distillation and Index of Refraction Determinations of Creosote Extracted from Pile No. 2

Temperature	Percentage weight of distillate			Average index of refraction of 2 and 3
	Section 1	Section 2	Section 3	
° C.				
235	4.0		6.0	1.5795
245	1.8	4.6	3.4	1.5825
255	1.6		3.2	1.5842
265	2.1	....	8.9	1.5872
275	2.1			
285	3.0	4.2	9.2	1.5945
295	2.4	2.2	3.1	1.5997
305	1.0	2.6	....	......
Residue	81.2	85.8	64.4	......

None of the sections contained an appreciable amount of light oils. The creosote from section 3 of pile No. 1, in which presumably less change in the character of the oil had occurred, contained 2.5 per cent of oils distilling below 205°. The same creosote contained over 40 per cent of naphthalene

oils (distilling between 205° and 255° C.). The other two sections of the same pile also contained considerable quantities of naphthalene.

The distillation of the creosote from pile No. 2 gave a very small percentage of distillate (below 305° C.) and a large amount of residue. The oil from section 3 (below the water line) of this pile, which yielded the largest amount of distillate, contained only 12.6 per cent of oils volatile below 255° C., and little or no naphthalene.

Sulphonation tests carried out on the fraction from 285° to 305° C. and 305° to 320° C. of the creosote from pile No. 1 failed to give any sulphonation residue. This oil resembles an imported creosote oil and is probably a pure coal-tar product. The index of refraction values of the fractions above 295° C. are a little low, but this could easily be due to the presence of a small amount of rosin which had escaped separation before the oil was analyzed. The color, odor and character of the fraction were like those of coal-tar creosote.

Sulphonation tests on the portions 285° to 305° C. of the creosote from pile No. 2 yielded a sulphonation residue of 2.6 per cent. The index of refraction values, as well as the color and odor, of this oil resemble those of water-gas-tar creosote. Later information on the testing of creosotes shows that this material could not be definitely identified as water gas tar creosote, and it may have been a pure coal tar creosote.

Change in Composition of the Creosote by Exposure

Inspection of Table 2 indicates that whatever loss of creosote occurred in the several sections through leaching and volatilization while the piles were in use must have occurred in the lighter fractions. If we assume that no change has occurred in the creosote extracted from section 3 of pile No. 1 (the portion buried in the mud) and that no change has occurred in the higher boiling fractions of the oil from the other two sections of this pile, the loss of oil in sections 1 and 2 may be computed as follows:

The fractions above 275° C. and residue for section 3 amount to 51.3 per cent of the total; the same portion of the creosote extracted from section 2 amounts to 59.1 per cent. If the oil from section 3 is unchanged, as assumed above, the original volume of the oil in section 2 can readily be obtained by the proportion $59.1:x = 51.3:100$, or $x = 115$ per cent. That is, the creosote extracted from section 2 is the residual of an oil that was originally 15 per cent greater in volume. By a similar computation it is found that the creosote extracted from section 1 is the residual of a creosote originally 35 per cent greater in volume.

The change in composition of the creosote from sections 1 and 2 is shown more fully in Table 4, in which the fractional distillation is computed on the basis of percentage of what is assumed to be the original oil.

Table 4—Fractional Distillation of Creosote Extracted from Pile No. 1 in Percentage of Assumed Original Oil

Temperature	Percentage weight of distillate		
	Section 1	Section 2	Section 3
° C. 225	1.5	15.8	30.8
245	·6.1	13.1	11.0
275	15.0	6.2	6.4
320	20.5	18.0	19.0
Residue	30.8	33.4	32.3

Table 4 shows that the loss of creosote in that portion of the pile in the water as compared with the loss from the portion buried in the mud was confined to the fraction distilling below 225° C. and that the loss from the portion in the air occurred only in the fractions below 245° C. The small excess of distillate between 225° and 245° C. in the creosote from section 2 over that for the same fraction from section 3 may be accounted for by the effect which the absence of some of the lower boiling constituents at

the lower stages of the distillation produce upon the fractionation of the large excess in the distillate between 245° and 275° C. of the oil from section 3.

Allowing for the losses as computed above, sections 1 and 2 of this pile originally had 16.1 and 17.6 pounds, respectively, of creosote per cubic foot of the treated portions. Section 2 thus agrees very well with section 3 (see Table 1). But the figure for section 1 is so much at variance with the figures for sections 2 and 3 that this section probably lost creosote in such a manner as to leave the composition of the residual oil unchanged, as by "bleeding." The original volume of oil must therefore have been more than 35 per cent greater than the present.

Similar changes occurred in pile No. 2, except that in this case section 2, which is the portion at the water line, changed most. This may be due to its position, where it was subject to the influences both of sun and water; and also to the fact that, being riddled by *Teredo*, more opportunity was afforded for leaching of the creosote.

Summary

Practically no light oils (oils distilling below 205° C.) were found in the piles after their long period of service. If originally present, they were lost by volatilization and leaching.

The creosote in the pile which was perfectly preserved contained originally at least 40 per cent of naphthalene fractions, a large portion of which remained in the wood. The creosote in the pile, which was less perfectly preserved, contained little or no naphthalene.

The pitchy matter, which on distillation formed the residue above 320° C. (pile No. 2), is seemingly of an inert character and little objectionable to *Teredo*. A heavy treatment with creosote consisting largely of this material did not entirely save the pile from attack.

Loss of oil from that portion of the pile in the water, in the case of the creosote in pile No. 1, which is a pure coal-tar creosote, apparently occurred only in the fraction distilling below 225° C.

Similar analyses have been made of sections of piles sent to the office of the Committee from various harbors. These analyses were made in the laboratory of the Barrett Company through the courtesy of Mr. Sumner R. Church, manager of the Research Department of that company. The methods used by the Barrett Company and by Mr. Mattos in the Southern Pacific laboratory, were similar and are described as follows:

The specimens were reduced to shavings, placed in a refluxing apparatus of the Soxhlet type, and extracted with benzol. The creosote extracted from each specimen was freed from benzol by distillation and tested for specific gravity, tar acids, naphthalene, and indices of refraction on fractions, float test on residue and unsulphonated residue. The nature of fractions was also noted. The specimens were weighed and measured before extraction, but the measurement included the holes in the pieces (made by shipworms) which made the calculation of "pounds creosote per cubic foot" an approximation only.

Specimen No. 1—From Warehouse No. 1 of Norfolk and Western Railway at Lamberts Point, Va. Pile driven in 1890 and said to have been treated under specifications requiring 22 pounds of creosote per cubic foot. Pile was pine, and section was cut from portion in water. Live shipworms were extracted in November, 1922.

Specimen No. 2—From Warehouse No. 2 of Norfolk and Western Railway at Lamberts Point, Va. Creosoted under same specifications as Specimen No. 1 and driven in 1892. Section cut from pine pile between low water and mud line. Pile had been attacked by shipworms, and pallets and shells were found in it in November, 1922.

Specimen No. 3—From Coal Pier No. 2 fender system Norfolk & Western Railway, Lamberts Point, Va. Pile and treatment same as No. 1 and No. 2. Section cut 1½ feet above mean low water. No borers found.

Specimen No. 4—From Pensacola Naval Station, Pensacola, Fla. Pine pile driven in 1902. (Fig. 26.) Specifications required absorption of 20 pounds of creosote per cubic foot. One hundred and ninety-eight piles in structure. In 1906 five piles were so badly damaged as to require renewal, and entire structure is now unsafe. Destruction was caused mainly by *Bankia* and *Limnoria*.

Creosote Analyses of Specimens Nos. 1 to 4

	Spec. No. 1	Spec. No. 2	Spec. No. 3	Spec. No. 4
Volume extracted	66.9 cu. in.	93.0 cu. in.	49.5 cu. in.	74.3 cu. in.
Weight extracted (dry)	363.4 gr.	663.2 gr.	414.3 gr.	561.5 gr.
Weight creosote extracted	23.6 gr.	24.9 gr.	55.5 gr.	106.7 gr.
Per cent creosote extracted by weight	6.5	3.8	13.1	18.8
Pounds creosote per cubic foot	1.4	0.9	4.2	5.5
Per cent water	4.4	4.5	5.2	5.4
Specific gravity 38/15.5° C.	1.051	1.040	1.041	1.081
Tar acids	Trace	...	None	None
Per cent naphthalene	8.2	*	8.3	None
Spec. grav., 235° C. to 315° C. 38/15.5° C.	1.013	1.010	1.023	1.015
Spec. grav., 315° C. to 355° C. 38/15.5° C.	1.088	1.059	1.086	1.025
Index of refraction of frac. 210° C. to 235° C. @ 60° C.	1.542	1.579	1.577	1.546
Index of refraction of frac. 235° C. to 315° C. @ 60° C.	1.592	1.594	1.590	1.581

* Not determined. Insufficient oil.

Unsulphonated Residue Fraction

235° C. to 315° C.	...	2.4%	...	...
315° C. to 355° C.	...	1.2%	...	...

Distillation Tests

	Spec. No. 1		Spec. No. 2		Spec. No. 3		Spec. No. 4	
Up to 170° C.	0.00		0.00		0.00			Trace
Up to 200° C.	Trace	liquid		Trace	0.00		0.00	
Up to 210° C.	3.0	solid	0.8	liquid		Trace	0.4	liquid
Up to 235° C.	8.9	solid	4.7	solid	6.4	solid	1.9	liquid
Up to 270° C.	25.8	solid	18.2	solid	36.2	semi-solid	10.0	liquid
Up to 315° C.	46.9	liquid	36.1	liquid	56.6	liquid	25.5	liquid
Up to 355° C.	73.0	solid	69.6	solid	80.4	solid	72.1	liquid
Float test—residue @ 70° C.	38	sec.	28	sec.	23	sec.		Too hard

Specimen No. 5—From Structure No. 1, Naval Wharf at St. Thomas, Virgin Islands. Pine pile section cut at point 9 feet below mean water level. (Fig. 27). Piles were treated with 16 pounds of creosote, driven in 1918, and removed in 1922, being practically destroyed by shipworms.

Fig. 26—Section of Pile from Pensacola Navy Yard Showing Work of Marine Borers.

One hundred and ninety-eight of these piles treated with 20 lb. per cu. ft. creosote were driven in 1902. At the end of three years five were badly attacked, necessitating the removal of two. Report of September, 1922, states that "all of the piles driven in the work are in such condition that quite a few have been broken off at about approximately water level by wave action. A large majority of the remainder can be broken off at the same level without much difficulty."

FIG. 27—SECTION FROM CREOSOTED PINE PILE—16 LB. TREATMENT—U. S. NAVAL STATION, ST. THOMAS, V. I.

Driven 1918—Removed 1923. Section immediately below low water

Specimen No. 6—Pile from same lot as No. 5, delivered at St. Thomas but not driven. Has been exposed to weather since 1918.

Specimen No. 7—From pile from Pier No. 1, San Juan, Porto Rico, driven in June, 1917, and removed September 21, 1922. Pine pile treated at Gulfport, Miss., under specifications requiring 16 pounds absorption per cubic foot. Section cut at the mud line. This section was cut up in order to secure biological specimens; it was heavily attacked by shipworms, *Martesia* and *Limnoria.*

Specimen No. 8—From Lighthouse Pier at San Juan, Porto Rico. No record of treatment available. (Fig. 28). It had 8 years' service and was destroyed by *Limnoria.* It was cut up for other species and none were found.

Creosote Analyses of Specimens Nos. 5 to 8

	Spec. No. 5	Spec. No. 6	Spec. No. 7	Spec. No. 8
Pounds creosote per cubic foot.	3.8	17.4	7.6	8.0
Per cent water..............	8.4	11.6	3.6	3.3
Specific gravity 38.5/15 5° C..	1.107	1.108	1.078	1.061
Tar acids—per cent..........	2.5	6.0	Not determined	Trace
Per cent naphthalene	6.8	None	None	None
Spec. grav., 235° C. to 315° C.. 38/15.5° C.	1.015	1.011	....	....
Spec. grav., 315° C. to 355° C.. 38/15.5° C.	....	1.068	....	....
Index of refraction of frac. 0° C. to 170° C. @ 60° C..	....	....	1.485	1.500
Index of refraction of frac. 170° C. to 200° C. @ 60° C..	....	....	1.490	1.500
Index of refraction of frac. 200° C. to 210° C. @ 60° C..	1.545	1.563	1.488	1.505
Index of refraction of frac. 210° C. to 235° C. @ 60° C..	1.568	1.562	1.490	1.521
Index of refraction of frac. 235° C. to 270° C. @ 60° C..	1.584	1.575	1.510	1.568
Index of refraction of frac. 270° C. to 315° C. @ 60° C..	1.601	1.592	1.587	1.582
Index of refraction of frac. 315° C. to 355° C. @ 60° C..	....	1.626	1.593	1.600
Unsulphonated residue	None	0.8%	4.0%	5.6%

Distillation Tests

	Spec. No. 5	Spec. No. 6	Spec. No. 7	Spec. No. 8
0° C. to 170° C.....	....	0.1%	2.3% liquid	0.7% liquid
170° C. to 200° C.....	0.1%	0.2%	4.6% liquid	1.6% liquid
200° C. to 210° C.....	0.4%	0.3%	5.2% liquid	2.3% liquid
210° C. to 235° C.....	7.0% solid	1.6% liquid	7.5% liquid	5.2 % liquid
235° C. to 270° C.....	29.3% semi-solid	12.4% liquid	12.8% liquid	17.6% liquid
270° C. to 315° C.....	44.4% semi-solid	33.2% liquid	31.5% liquid	36.1% liquid
315° C. to 355° C.....	61.8% greasy	59.2% partly solid	51.4% semi-solid	63.1% waxy solid
Float test — residue at 70° C.	137 sec.	48 sec.	40 sec.	96 sec.

Specimen No. 9—Section of pine pile from foundation of 150-ton revolving crane at the plant of the Newport News Shipbuilding Company. (Fig. 29). These piles were treated by the Norfolk Creosoting Company in 1897 with a 16-pound treatment. The creosote was purchased under the following specification:

> "All oil shall be the heavy or dead oil of coal tar, containing not more than 1½% of water, and not more than 5% of tar, and not more than 5% of carbolic acid.
>
> "It must not flash below 185° F. nor burn below 200° F. and it must be fluid at 118° F.
>
> "It must begin to distill at 320° F. and must yield between that temperature and 410° F., of all substances, less than 20% by volume.
>
> "Between 410° F. and 470° F. the yield of naphthalene must be not less than 40% nor more than 60% by volume.
>
> "At two degrees above its liquefying point it must have a specific gravity of maximum 1.05 and minimum 1.015."

FIG. 28—SECTION OF CREOSOTED PILE FROM LIGHTHOUSE WHARF, SAN JUAN, PORTO RICO, TAKEN FROM LOW WATER LINE.
Built, 1898—Renewed, 1906

On account of the importance of this foundation it has been inspected frequently and carefully. Shipworm attack first appeared about 1920, or after 23 years' service, and the pile analyzed was removed in 1922, after 25 years' service.

The report of the extracted creosote follows:

TESTS ON CREOSOTE RECOVERED FROM MARINE PILING

Pounds of creosote per cu. ft.................. 6.9
Specific gravity 38/15.5° C. 1.051

RETORT DISTILLATION

		Sep. Percentage	Totals Percentage	Nature
	170° C.	0.0	0.0	
	200	0.0	0.0	
(410° F.)	210	0.0	0.0	
	235	7.0%	7.0%	Solid
(470° F.)	243.5	11.1	18.1	Solid (18.7% by vol. See Spec.)
	270	19.6	37.7	Solid—liquid
	315	17.3	55.0	Liquid
	355	23.5	78.5	Solid
	Residue	20.3	98.8	
	Loss		1.2	

Tests on Fractions	Sp. Gr. 38/15.5° C.	Index of Refraction of Frac. 60° C.	Unsulfonated Residue
210-235° C.	....	1.581	....
235-315° C.	1.021	1.592	3.3%
315-355° C.	1.052	....	2.4%

Float Test on Residue 70° C.—65 seconds
Tar acids, by contraction 9.8%
by liberation 7.9%
% Naphthalene 9.6 (32% of Distillate to 250° C.)

The naphthalene content of the extracted creosote indicates that in all probability the specifications were complied with, and it is of interest to note that, while a large portion of the low boiling components of the original creosote are no longer present, a considerable amount of naphthalene remains after the 25 years of service.

The Turtle River Docks of the Southern Railway at Brunswick, Ga., were built in sections at different times, and the Committee has been so fortunate as to secure specimens from piles driven in 1909 and 1913, and with them to obtain an unusually good record of their treatment, and an analysis of four specimens cut from the 1909 piles as made by the Forest Service in September, 1909.

In September, 1923, two specimens each of the 1909 and 1913 piles were sent the Committee by the Southern Railway, and these specimens were analyzed by the Barrett Company under the direction of Mr. S. R. Church, whose report follows:

OBJECT: To extract and test creosotes from four sections of marine piling from Brunswick, Ga.

ABSTRACT: Specimens No. 1 and No. 2 contained 3.0 and 3.3 pounds of creosote per cubic foot, while specimens No. 3 and No. 4 contained 3.7 and 2.8 pounds per cubic foot respectively. The tests on the extracted creosotes, in general, compare favorably with the original oils, considering their time of exposure, particularly in the case of piles No. 1 and No. 2.

The extracts from No. 1 and No. 2 are typical coal tar distillates containing considerable naphthalene. The extract from No. 3 inner layer yielded 38% of naphthalene. The creosote from No. 4 yielded but 8.2% of naphthalene.

In general the outer layers of the specimens yield creosotes heavier in gravity and distillation and containing less naphthalene and tar acids than the inner layers.

Four specimens of marine piling were received from the Committee on Marine Piling Investigations of the National Research Council for examination. The identification of the sections is as follows:

All four specimens of the piling were cut from the Turtle River Docks of the Southern Railway at Brunswick, Ga. Two sections (marked No. 3 and No. 4) were driven in the summer of 1909 while the other two sections (marked No. 1 and No. 2) were from a group of very carefully selected piles with open grain and considerable sap wood. These were driven in 1913 and were reported to have been handled and driven with extreme care to prevent damage and that all skin had been removed from them. These two were also partly seasoned in a stack of piling for two months. Piles No. 3 and No. 4 were treated in May and June, 1909, at the Southern Creosoting Company's plant at Brunswick, Ga., and the other two were treated at the same plant in November, 1913. The tests on the creosotes used and the treatment given the piles are given in the data.

The tags on the specimens received were marked as follows:

Specimen No. 1—Cut out at half way between high and low water mark.

Specimen No. 2—Cut out half way between low water and mud line.

Specimen No. 3—Cut out at mean low water line. (*See note.)

Specimen No. 4—Cut out at mean low water line. (*See note.)

The specimens were carefully examined and calipered after which they were photographed. The water determinations on the total specimens were run, using the Dean & Stark apparatus, and are based on radial borings which represent an average sample of the pile. The pounds per cubic foot are based on careful measurements and extractions but these would necessarily be approximations since the measurements would include any holes in the pieces. These determinations were also made on "outer" and "inner" layers of the creosoted portions of the piles, the outer half of the creosote ring being called the "outer layer" while the inner half of the creosote ring is termed the "inner layer." These layers were reduced to shavings and extracted separately with benzol in a refluxing apparatus of the Soxhlet type after which the benzol was carefully distilled from the extracted oils. The following tests were run on the oils: Specific gravity, retort distillation noting nature of fractions, indices of refraction of fractions, specific gravity of fractions, float test on residue, per cent tar acids, per cent tar bases, per cent naphthalene and unsulphonated residue.

Inasmuch as specimen No. 4 was a comparatively small sample and the inner and outer layers were both attacked by *Teredo* to the same extent the total combined creosote was tested in this case.

Condition of Wood and Preservation of Piling

Specimen No. 1—Attacked slightly by *Limnoria* on one side and slightly roughened in few spots possibly by contact with boats. The pile otherwise was in an excellent state of preservation. The specimen had evidently developed slight cracks since it was cut. There were no borer holes. (Fig. 30.)

Specimen No. 2—This pile had not been attacked either by *Limnoria* or *Teredo*. With the exception of slight cracks which had developed since the specimen was cut, it was entirely smooth and in an excellent state of preservation. (Fig. 31.)

Specimen No. 3—This pile had been badly attacked by *Limnoria* and also

*Note: Specimens No. 3 and No. 4 were marked alike as above but Mr. T. G. Townsend states that, from the measurements, it looks as if No. 4 should be from between high and low water and No. 3 from between low water and bottom.

contained a few borer holes. Its surface was considerably indented from the results of the attack by *Limnoria*. (Fig. 31.)

Specimen No. 4—A large portion of this pile had been eaten away by *Teredo*. Both the heart wood and the creosote layer were seriously attacked and the specimen was very reticular in structure. It was in a poor state of preservation. (Fig. 30.)

Measurements of Specimens

The following measurements were taken by Mr. T. G. Townsend:

Specimen	No. 1	No. 2	No. 3	No. 4
Average diameter (inches)	12¾	11¾	10	12
Age in years	102	95	55	60
Summerwood (approximate percentage)	40	40	..	..
Number of rings in 3d, 4th and 5th inch from center	49	60	47	36
Average number of rings per inch in 3d, 4th and 5th inch from center	16	20	16	12
Percentage of summerwood in 3d, 4th and 5th inch from center	40	40	40	60
Rings from Center				
1st inch	6	7	3	4
2d inch	10	12	5	4
3d inch	14	18	6	9
4th inch	18	16	9	13
5th inch	17	21	32	14
6th inch (In No. 2—⅞")	24	21	..	16
(In No. 1—⅜")	13	..	..	..
Rings from Surface				
1st inch	28	28	32	16
2d inch	20	20	9	14
3d inch	16	16	6	13
4th inch	16	16	5	9
5th inch	12	11	3	4
6th inch (In No. 2—⅞")	8	4	..	4
(In No. 1—⅜")	1	..	..	..
Creosote Ring				
Depth in inches	2¾	2¾	2¾	2¾
Number of rings	60	60	44	34
Average per inch	22	22	16	12
Summerwood	40	40	40	50

Treatment of Piles

The piles are reported to have been treated as follows:

Piles Driven in 1913 (No. 1 and No. 2)—Steam 10 hours at 30 pounds, vacuum 3 hours at 26", oil four hours at 160 pounds, 160° F. Three were re-treated with 20 pound charge on account of damage. Partly seasoned in stack of piling for two months, and all were in good condition. All skin removed. The treatment was 18 pounds per cubic foot with a combination of Barrett and English oils. It is not known whether samples submitted are from three re-treated piles or not.

Piles Driven in 1909 (No. 3 and No. 4)—A treatment of 16 pounds per cubic foot was given these piles.

Previous Analysis of Piles

Four specimens cut from the piles treated in 1909 were analyzed by the Forest Service in September, 1909. The results of these analyses along with an average analysis of the original oil are as follows:

	Avg. Analysis of Orig. Oil	Forest Service Analysis			
Specimen		A	B	C	D
Pounds per cubic foot	16.	6.7	7.4	12.5	17.2
Specific gravity	1.055	1.066	1.060	1.070	1.073
Water	4%	....	....	....	....
Distillation Fractions					
0–205	....	2.0%	2.0%	1.5%	2.5%
205–245	....	43.0	43.0	37.5	37.5
245–275	....	7.5	9.0	11.0	11.0
275–305	....	13.5	10.0	9.0	11.5
305–320	....	7.5	6.0	7.0	7.0
0–200° C.	2.0%				
200–210	3.0				
210–235	28.0				
235–355	57.0				

Fig. 29—Pile Section with 16 Lb. Creosote Treatment. 25 Years' Service in 150 Ton Crane Foundation, Newport News Shipbuilding & Dry Dock Co., Newport News, Va.

ANALYSIS OF SPECIMENS

Specimen	No. 1						No. 2						Test on Original Oil
Layer	Outer			Inner			Outer			Inner			
Total Specimen													
Lbs. Oil Per Cu. Ft.	3.0						3.3						18
% Water	17.0						17.2						....
Layers													
Lbs. Oil Per Cu. Ft.	4.2			4.5			5.4			6.1			....
% Water	6.7			7.2			6.0			7.6			....
Tests on Extracted Oils													
Sp. Gr. 15.5° C.	1.099			1.082			1.093			1.084			1.072
% Water	.....			.....			.....			.....			1.5
Retort Distillation	%	Nature	Index of Ref. 60° C.	%	Nature	Index of Ref. 60° C.	%	Nature	Index of Ref. 60° C.	%	Nature	Index of Ref. 60° C.	%
% to 200° C.	0	......	....	0	......	....	....	......	....	....	......	....	1.0
210°	0	......	....	0	......	....	....	......	....	....	......	....	2.0
235°	2.4	Solid	1.589	10.6	Solid	1.588	0.9	Solid	1.585	8.9	Solid	1.586	18.0
270°	23.0	80% Solid	1.606	39.5	95% Solid	1.604	21.5	Solid	1.594	38.7	Solid	1.595	44.0
315°	46.6	50% Solid		57.6	Solid.....		46.2	50% Solid	1.613	56.2	50% Solid	1.613	59.0
355°	77.9	Solid	....	82.7	Solid	....	76.9	Solid	....	80.7	Solid	....	79.0
Float Test Res. 70° C.	32 Sec.			37 Sec.			31 Sec.			26 Sec.			....
Sp. Gr. Fract. 38/15.5° C.													
235-315° C.	1.039			1.035			1.034			1.031			....
315-355°	1.117			1.100			1.103			1.098			....
% Naphthalene	7.0			17.2			6.2			17.1			....
% Tar Acids	0.5			1.2			1.4			3.1			....
% Tar Bases	None			None			None			None			....
% Unsul. Residue	None			None			None			None			....

ANALYSIS OF SPECIMENS

Specimen	No. 3						No. 4			Test on Original Oil
Layer	Outer			Inner			Outer	Inner		
Total Specimen										
Lbs. Oil Per Cu. Ft.	3.7							2.8		16
% Water	22.0							7.2		....
Layers										
Lbs. Oil Per Cu. Ft.		4.0			5.9		4.1		4.3	....
% Water		6.4			8.0		6.4		6.4	....
Tests on Extracted Oils										
Sp. Gr. 15.5° C.		1.064			1.052			1.071		1.055
% Water		.....			.....		.....		.....	4.0
Retort Distillation	%	Nature	Index of Ref. 60° C.	%	Nature	Index of Ref. 60° C.	%	Nature	Index of Ref. 60° C.	%
% to 200° C.	0	......	....	0	......	....	0.2	....	....	2.0
210°	0	......	....	0	......	....	1.0	Semi-solid	1.571	5.0
235°	11.3	Solid	1.588	45.5	Solid	1.592	6.8	Semi-solid	1.575	33.0
270°	42.0	Semi-solid	1.594	69.3	Solid	1.597	31.6	Semi-solid	1.589	....
315°	64.1	Semi-solid	1.606	80.5	Semi-solid	1.610	54.1	Liquid	1.600	....
355°	84.4	Solid	1.643	92.2	Solid	1.635	(60.9@ 328°C. decomp)	Solid	1.612	90.0
Float Test Res. 70° C.		107 sec.			113 sec.			Too soft		Soft
Sp. Gr. Fract. 38/15.5°C.										
235-315° C.		1.016			1.027			1.011		
315-355°		1.042			1.096			.....		
% Naphthalene		17.5			38.0			8.2		
% Tar Acids		2.3			0.8			Trace		
% Tar Bases		None			None			None		
% Unsul. Residue		None			Trace			Trace		

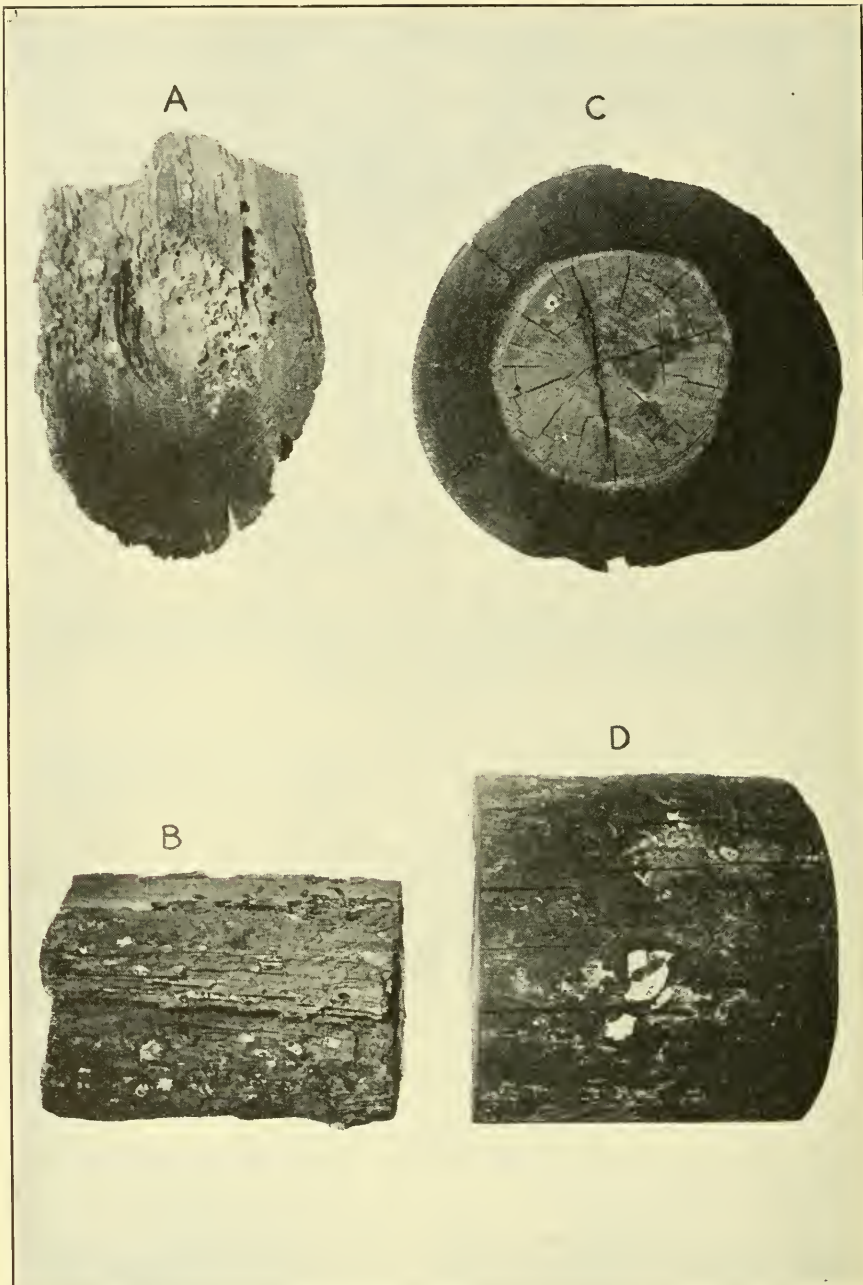


Fig. 30—Pile Sections from Turtle River Docks, Southern Ry., Brunswick, Ga.

A. B.—Pile driven in 1909.
C. D.—Pile driven in 1913.

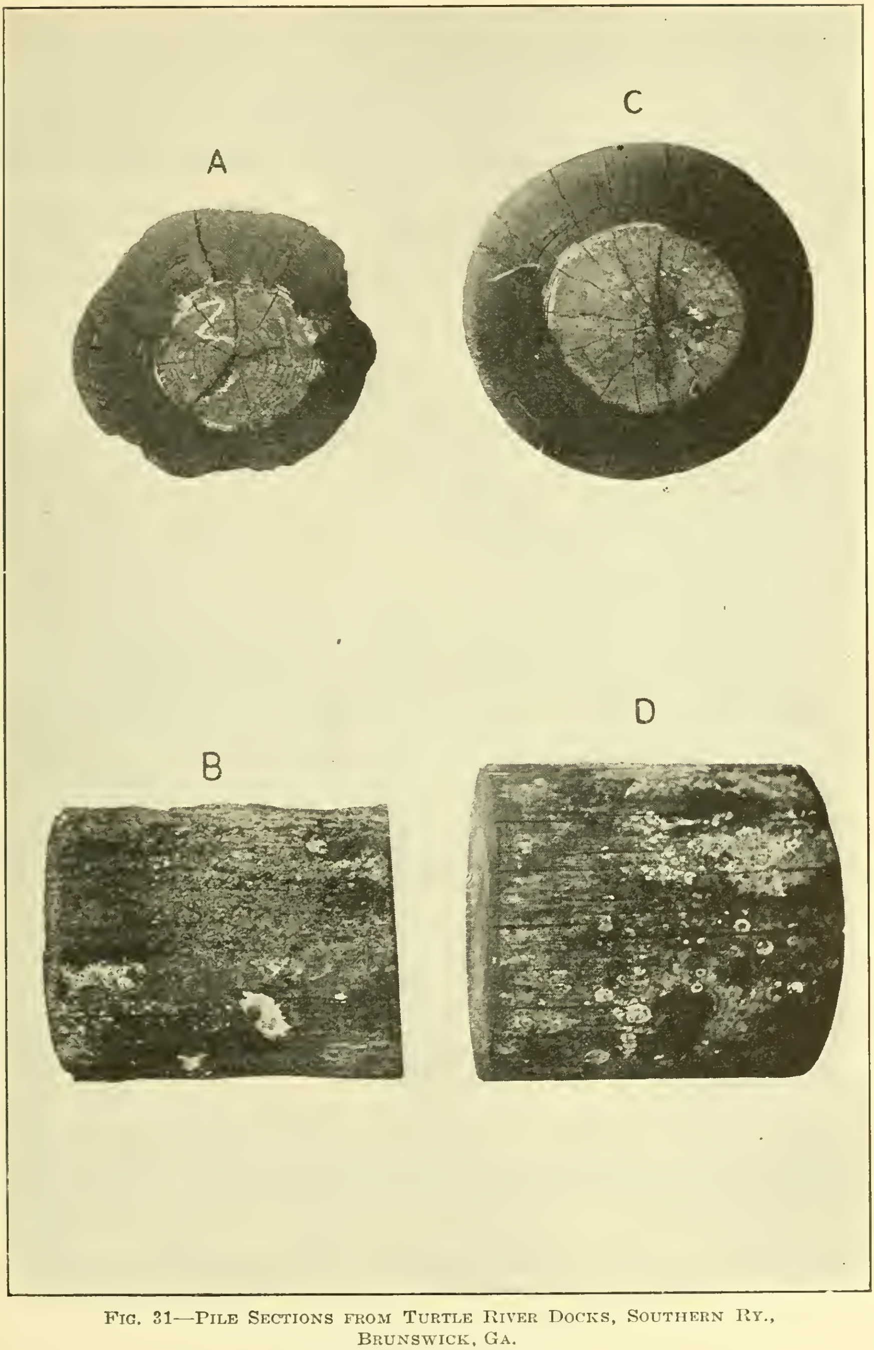


FIG. 31—PILE SECTIONS FROM TURTLE RIVER DOCKS, SOUTHERN RY., BRUNSWICK, GA.

A. B.—Pile driven in 1913
C. D.—Pile driven in 1909

Observations

Piles No. 1 and No. 2 contained 3.0 and 3.3 pounds per cubic foot of creosote while No. 3 and No. 4 contained 3.7 and 2.8 pounds per cubic foot respectively and the outer layers contained slightly less creosote in each case excepting No. 4 which contained the same amount in both layers. No. 4 pile, however, was so badly eaten away that both layers were evidently exposed to the same conditions. This reticular structure would also account for the low water content of this specimen.

The oils obtained from piles No. 1 and No. 2 are typical coal tar distillates having low float tests on residue. The extracted oils are somewhat heavier in gravity and distillation than the original oil since they have probably lost some of their lighter portions during their long exposure but the distillation tests, particularly on the inner layers, compare favorably with the distillation on the original oil. The oil fractions obtained were largely solid in nature, even the 315° C. fraction containing considerable solids. The oils from No. 1 and No. 2 piles are particularly characterized by their naphthalene content, especially the inner layers, which contained slightly over 17 per cent. The outer layers contained between 6 and 7 per cent. The original oil evidently contained considerable naphthalene. The tar acid contents were 0.5 per cent and 1.4 per cent on the outer layers and 1.2 per cent and 3.1 per cent on the inner layers. It appeared during the determination of the tar acids that these results were possibly affected by a small quantity of wood distillate obtained with the oils during their extraction. The oils from these 1913 specimens contained neither tar bases nor unsulphonated residue.

The oils obtained from piles No. 3 and No. 4 are also heavier in gravity and distillation than the original oil with the exception of the inner layer of pile No. 3, which yields a higher percentage of distillate at 235° C. and 355° C. and is lower in gravity. This may be due to the presence of wood distillate which possibly accounts for the comparatively high float tests on residue obtained on pile No. 3 oils and also the low gravity of distillates. The oils from pile No. 4 decomposed at 328° C. and gave a low gravity of distillate, which is also due, no doubt, to resinous material extracted with the oil. Pile No. 3 is particularly characterized by its very high naphthalene content, especially in the oil from the inner layer, which contained 38 per cent as compared to 17.5 per cent in the outer layer. Pile No. 4 oil contained but 8.2 per cent of naphthalene and a trace of acids as compared to 2.3 per cent acids in the outer and 0.8 per cent in the inner layers of No. 3. The tar acid determinations are probably affected to some extent by unavoidable presence of extracted material extracted from the wood itself.

The oils from the outer layers in general are heavier in gravity and distillation than the inner layers and contain less naphthalene and acids with the exceptions as stated above. The comparatively large differences obtained between the oils from the inner and outer layers of specimen No. 3 are probably due to the fact that this pile was mainly attacked by *Limnoria*, which made the outer layer somewhat reticular in structure while the inner layer, though attacked slightly by borers, was comparatively but little affected.

The analysis of extracted creosote does not give exact results because of the impossibility of entirely separating the extracted creosote from the resinous wood products extracted at the same time, but a study of the results gives some idea of the rapidity of leaching at the several locations. These results must be considered with the facts of organic variation in mind, since the selection of one pile from a series treated may result in the analysis of a pile from either extreme. For purposes of comparison the amount of creosote supposed to be injected and the amount recovered are listed below, using the results of analysis of the pile sections cut below the mud line as the amount of oil originally injected, where this information is available.

Specimen No.	Length of Service	Original Impregnation Lbs. per cu. ft.	Amount Extracted Lbs. per cu. ft.	Remarks
No. 1 San Francisco, Cal......	29 years	14.17	9.97	Pile good—Bethell process
No. 2 San Francisco, Cal......	22 years	10.00	3.18	Pile good—Isaacs & Curtis process.
No. 3 San Francisco, Cal......	20 years	10.00	3.78	Pile good—Isaacs & Curtis process.
No 4 San Francisco, Cal......	18 years	10.00	4.51	Pile good—Isaacs & Curtis process.
No. 27 San Francisco, Cal......	29 years	15.19	7.52	Pile good—Bethell process
No. 3 San Francisco, Cal......	....	8.59	8.22	Pile good
No. 10 San Francisco, Cal......	....	4.75	4.35	Pile attacked
No. 37 San Francisco, Cal......	....	6.87	6.30	Pile good
No. 1 Galveston, Texas (1875)	29 years	9.25	6.12	Pile good
No. 2 Galveston, Texas (1875)	29 years	10.05	6.49	Pile heavily attacked
No. 3 Galveston, Texas (1895)	18 years	10.60	9.14	Pile good
No. 4 Galveston, Texas (1895)	18 years	9.28	6.38	Pile attacked
No. 6 Galveston, Texas (1895)	18 years	15.72	8.83	Pile good
No. 1	30 years	12	10.7	Pile good—Bethell process
No. 2 Biloxi, Miss.............	31 years	11.5	5.8	Heavy attack — Bethell process
No. 1 Lamberts Point, Va.....	32 years	22	1.4	Light shipworm attack
No. 2 Lamberts Point, Va......	30 years	22	0.9	Light shipworm attack
No 3 Lamberts Point, Va......	30 years	22	4.2	Pile good—Section 1½ ft. above L. W.
No. 4 Pensacola, Fla.........	20 years	20	5.5	Attacked in four years. Totally destroyed 20.
No. 5 St. Thomas, V. I........	4 years	16	3.8	Piles destroyed
No. 6 St. Thomas, V. I........	4 years	16	17.4	Piles stored in air
No. 7 San Juan, P. R.........	5 years	16	7.6	Piles destroyed
No. 8 San Juan, P. R.........	8 years	..	8.0	Piles destroyed by *Limnoria*
No. 9 Newport News, Va......	25 years	16	6.9	Heavy shipworm attack
No. 1 Brunswick, Ga..........	10 years	18	3.0	Slight *Limnoria* attack
No. 2 Brunswick, Ga..........	10 years	18	3,3	Unattacked
No. 3 Brunswick, Ga..........	14 years	16	3.7	Heavy *Limnoria* — light shipworm attack
No. 4 Brunswick, Ga..........	14 years	16	2.8	Heavy *Limnoria* and shipworm attack

Of the specimens analyzed all except No. 4 (Pensacola) and possibly No. 7 and No. 8 appear to be coal tar creosote. The lower boiling fractions seem to have been leached out by the sea water much more rapidly than the higher ones, as was to be expected, but while the San Francisco specimens were unattacked with a minimum of 3.18 pounds of retained creosote per cubic foot, the Newport News specimen was rather heavily attacked with 6.9 pounds present. It does not appear probable that the Norfolk & Western piles from Lamberts Point could have been attacked until the creosote content was much lower.

Several structures were inspected by a sub-committee of the American Railway Engineering Association in 1920 and 1921, with the following results:

SOUTHERN RAILWAY—COAL PIER AT CHARLESTON, S. C.—This structure was built in the winter of 1914-15 with a mixture of longleaf, loblolly and shortleaf pine piles, treated at two plants with 18 pounds of creosote per cubic foot. Plant No. 1 used a mixture of English creosote and creosote furnished by the Barrett Company, and Plant No. 2 used English creosote, the average analyses being as follows:

	Plant No. 1	Plant No. 2
Specific gravity	1.08	1.044
Water	0.5%	2.0%
Fractions 0–200° C.	1%	1%
Fractions 200°–210° C.	1%	4%
Fractions 210°–235° C.	21%	16%
Fractions 235°–270° C.	21%	26%
Fractions 270°–315° C.	13%	19%
Fractions 315°–355° C.	20%	17%
Residue	Soft	Soft

The treatment at Plant No. 1 was ten hours steaming at a pressure of 35 pounds, three hours vacuum at 27 inches and three to six hours creosote pressure at 175 pounds, while at Plant No. 2 the steaming period was twelve hours at 30 pounds, the vacuum three hours at 24 inches, and the impregnation period two and one-half to four hours at 150 pounds.

After five years' service these piles showed a light attack by *Limnoria*, which had become heavy and destructive three years later. The life of the structure at this time was estimated to be two or three years longer or a total of about ten years.

Charleston Terminal Co. Wharf Built About 1880. These piles are reported to have been treated by placing them in a cylinder with the small end projecting. The open end of the cylinder was then sealed and creosote forced into the cylinder until it came out of the projecting end of the piles. In 1919 some of these piles had been cut off by *Limnoria* and spliced, but a large majority still had an effective diameter of 8 inches after about 40 years' service. This pier was burned in 1921.

The Clyde Line Piers at Charleston, S. C., were built in 1912-13, using shortleaf pine piles with a sap ring of over 3 inches. There were 22 pounds of English creosote injected, giving at least 3½ inches penetration, and a very superior treatment was secured. The analysis of the creosote was as follows:

Specific gravity	1.056
Water	1.5%
Fractions 0°–200° C.	0.0%
Fractions 200°–210° C.	2.0%
Fractions 210°–235° C.	25%
Fractions 235°–315° C.	39%
Fractions 315°–355° C.	20%
Residue	Soft

The piles were steamed twelve to fourteen hours at 35 pounds pressure, a vacuum of 27 inches was maintained for three hours, and the creosote pressure of 175 pounds was maintained for from four to six hours.

In 1919 a slight attack by *Limnoria* was reported, and reports from another source in 1922 stated that the attack was heavy and that the structure could not be expected to last more than 2 or 3 years longer.

In this structure the bracing, which received a 20-pound treatment was placed below low tide and the piles were somewhat damaged by rough handling, whereby the attack by the boring organisms was undoubtedly accelerated.

Southern Railway, Turtle River Docks, Brunswick, Ga.—These docks were built in four sections. The first was built in 1909, using a 16 to 18-pound treatment of high naphthalene creosote. The piles in this section were heavily attacked at the end of five years, and after ten years more were replaced and the others were in bad condition.

The second section was built in January, 1909, but the piles were treated in October and November, 1907, and were exposed to the air during these 13 or 14 months intervening between their treatment and the construction of the pier. The treatment was 16 pounds with creosote furnished by the Semet-Solvay Company with an analysis as follows:

Specific Gravity	1.06
Fractions 0°–200° C.	1%
Fractions 200°–210° C.	4%
Fractions 210°–235° C.	24%
Fractions 235°–315° C.	37%
Residue	34%

Attack was heavy at the end of three years, many piles were replaced by the end of five years, and all were useless in less than ten years. It is probable that the exposure of these piles before they were driven had something to do with their short life.

The third section, containing 930 piles, was constructed in 1909 with longleaf pine piles treated only a short time before they were used. The treatment consisted of twelve hours steaming at 40 pounds, four hours vacuum of 22 inches, and about four hours creosote pressure of 120 pounds. Sixteen pounds of English creosote were injected.

After three years' service there was a light attack by borers, after five years, a medium, and after ten years, a heavy attack.

A number of similar piles were treated at the same time and used at Pinners Point, Va., and in both cases the two-inch to three-inch sap ring was thoroughly treated. In 1922 the Pinners Point piles had all practically reached the end of their life. Four specimens cut from this group of piles were analyzed by the Forest Service in September, 1909, with results shown. (page 131).

Another group of 683 piles with similar creosote and treatment were driven in 1911-1912, which, after three years, showed no attack, and after eight years, medium attack.

In 1913 a group of 20 very carefully selected piles was treated with 18 pounds of mixed English and Barrett creosote by the following method: steam at 30 pounds for ten hours, 26-inch vacuum for three hours, and creosote at 160 pounds and 160 deg. Fahr. for four hours. These piles were handled and driven with extreme care to prevent damage, and in 1923 a few of them showed a slight attack by *Limnoria.*

With very few exceptions the character of the creosotes used in the original impregnation of most of these older piles is unfortunately unknown. It is therefore possible to draw only very general conclusions from the examination of extracted creosotes. The older piles were almost universally treated with what are known as high naphthalene creosotes, meaning thereby creosotes having 40 per cent or more of the 210 deg.-235 deg. C. fraction. This was particularly true of the piles treated with what were then known as English creosotes. In all probability the San Francisco piles, the Galves-

ton piles, and the Norfolk piles referred to above were treated with these types of creosotes. Attention is called, however, to the fact that some of the San Francisco piles were treated with creosotes having a lower naphthalene content (explained by the fact that in the original treatment the liquid portions of the creosotes only were used). Note also in this connection the analyses of creosote extracted from Long Wharf, Oakland, Cal., piles Nos. 1 and 37 (probably low naphthalene creosote) and piles Nos. 4 and 23 (probably high naphthalene creosote). The creosote which ran from the cavity in pile No. 1, Dock A, seems to confirm the idea that the creosote with which piles Nos. 1 and 37 were treated was of low naphthalene content. Bateman (Forest Service Circular No. 199) cites two piles, one well preserved, treated with high naphthalene content creosote, and another not so well preserved, treated with a low naphthalene creosote.

In recent years many piles have been treated with heavier creosotes of low naphthalene content, and there has been much discussion as to whether low or high naphthalene creosotes give the greater efficiency. Service records of piles treated with these two types of creosotes are most conflicting. The percentage of good piles in the Norfolk district treated with high naphthalene creosotes is very high. This is also so in the case of many of the Gulf coast piles. On the other hand the low naphthalene creosote piles Nos. 1 and 37 in San Francisco Bay were perfectly sound, while the high naphthalene creosote piles Nos. 4 and 23 had been attacked by *Limnoria.*

In spite of numerous analyses and attempts to deduce conclusions therefrom it is still an open question as to whether naphthalene is one of the essential constituents or not. What has been said for naphthalene applies with even more force to other constituents of creosote. Realizing the necessity for obtaining more definite information as to the influence of the various constituents of creosote, experiments were initiated in 1911, by the Forest Products Laboratory of the Department of Agriculture, with various fractions of creosote to determine which of them contained the necessary protective elements. For the purpose of this study creosote was divided into five fractions as follows:

I. Light creosotes distilling up to 205 deg. C. (401 deg. Fahr.).
II. Naphthalene solids distilling between 205 deg. C. and 250 deg. C. (401 deg. Fahr. to 482 deg. Fahr.).
III. Dead or golden oil distilling between 250 deg. C. and 295 deg. C. (482 deg. Fahr. to 562 deg. Fahr.).
IV. Anthracene solids distilling between 295 deg. C. and 320 deg. C. (560 deg. Fahr. to 608 deg. Fahr.).
V. Residue above 320 deg. C. (608 deg. Fahr.).

A number of pieces of timber were treated with each of these fractions and immersed in various harbors where borers were known to be active, with the results shown in the table on pages 142, 143.

It is evident that Fractions 1 and 2 are less efficient than the higher boiling fractions, and that the higher absorptions give better protection than the lower, but none of the fractions was more efficient than the creosote containing all of them.

Other series of experiments were started in 1914 with water gas tar creosote, copperized coal tar creosote, creosote with ferric chloride, zinc chloride and crude oil and copperized crude oil. All the specimens were de-

stroyed before the 1923 inspection, except the creosote copper and ferric chloride mixtures, both of which had been attacked.

In 1915 a series of test pieces were placed at Pensacola, Fla., and Gulfport, Miss., with the following results up to the 1923 inspection:

TREATMENT	ABSORPTION LBS. PER CU. FT.	RESULT
75% creosote, 25% naphthalene...	4.64 to 15.25	2 destroyed, 1 lost, 4 attacked, 1 sound.
50% creosote, 50% naphthalene...	6.73 to 17.02	4 destroyed, 2 lost, 2 sound.
75% creosote, 25% by-product tar	7.47 to 11.52	1 destroyed, 2 lost, 4 attacked, 1 sound.
50% creosote, 50% tar............	7.56 to 11.62	6 lost, of which 3 showed attack on previous inspections; 1 attacked, 1 sound.

Another series of tests was commenced in 1916 in which the impregnating fluids were creosote and crude oil with various additions. The test pieces were 2 inches x 2 inches x 18 inches, mostly sapwood which had a high rate of absorption and probably a correspondingly high rate of leaching.

The impregnation was from 5.2 pounds to 37.9 pounds per cubic foot, and all but one specimen have been attacked and two were destroyed in 41 months.

Specimens treated with from 15.9 pounds to 40.2 pounds water gas tar also had one unattacked test piece with one destroyed in 82 months, one heavily attacked in 56 months and then lost, and the others all attacked.

Specimens treated with crude oil from 26.2 pounds to 33.0 pounds were all destroyed in 41 months.

The test pieces treated with creosote and water gas tar with the addition of 1 per cent copper in the form of copper oleate showed very slight improvement over those which did not contain the copper, but the same addition to crude oil extended the life of two of the five test pieces one year.

Several other series were included in the 1916 tests in which various mixtures were used, but no conclusive results have yet been obtained except that the addition of crude oil to creosote or tar shortens the life of the timber about in the proportion of the amount of oil added to the creosote.

In 1918 test series were impregnated with creosotes of varying compositions, but there is not enough evidence as yet on which to base a conclusion.

The Forest Products Laboratory also initiated a series of tests of the different fractions of creosote on the Pacific Coast in 1911 similar to those on the Gulf. The test pieces were immersed in San Diego and San Francisco Bays, and while the tests are not conclusive they appear to confirm the results of the Gulf Coast tests, i.e., that when used alone the higher boiling fractions are more effective than those with the lower boiling points.

The Forest Products Laboratory tests just referred to used the individual fractions by themselves. Realizing that creosotes with the individual fractions removed might give different results, another set of experiments was initiated in 1921 by the San Francisco Bay Marine Piling Committee (see Proceedings American Wood Preservers' Association, 1922, page 394) in

FOREST SERVICE SPECIMENS INSTALLED AT GULFPORT, MISS., AND PENSACOLA, FLA., IN 1911 AND 1912. (SPECIMENS ABOUT 6 INCHES IN DIAMETER AND 24 INCHES LONG.) LAST INSPECTED JANUARY, 1923

Specimen Number	Treated with	Absorption (Lbs. per cu. ft.)	Species	Location	Date placed in test	Description of attack by borers: Sound or slight	Medium	Severe	Destroyed: Date recorded as destroyed	No. of months in test before removal
153		5.20	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	Jan., 1914	22
155		6.20	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	Feb., 1917	59
151		6.40	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	....	Aug., 1919	89
4		7.68	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	....	....	Jan., 1915	48
150	Fraction	8.20	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	....	Feb., 1917	59
149		9.20	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	....	Feb., 1917	59
154	1	9.40	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	Feb., 1917	59
152		10.2	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	....	Aug., 1919	89
156	Creosote	13.10	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	Jan., 1921	106
2		10.65	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	....	....	Feb., 1917	73
3		11.83	Loblolly pine	Pensacola, Fla.	Jan. 1911	....	....	....	Jan., 1923	144
1		13.48	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	....	....	....	Lost
145		2.10	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	Jan., 1914	22
142		2.30	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	....	Jan., 1914	22
144		5.20	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	....	Aug., 1919	89
141		6.60	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	....	March, 1916	48
148	Fraction	6.80	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	Jan., 1914	22
143		7.10	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	....	Aug., 1919	89
146	2	7.20	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	Feb., 1917	59
147		9.40	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	Aug., 1919	89
19	Creosote	6.08	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	....	....	Aug., 1919	103
20		14.28	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	....	....	....	Lost
17		14.68	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	....	....	....	Lost
18		15.58	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	....	X	....	....
117		3.40	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	....	Jan., 1914	22
119		6.20	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	....	Jan., 1923	130
118		6.90	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	....	Aug., 1919	89
121		6.90	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	....	Lost
122	Fraction	7.10	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	Aug., 1919	89
120		7.50	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	Nov., 1921	116
124	3	7.60	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	Aug., 1919	89
123		7.90	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	Aug., 1919	89
9	Creosote	13.28	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	....	X	....	....
11		14.13	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	....	X	....	....
12		15.36	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	....	....	....	*
10		16.41	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	....	X	....	....

109		4.50	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	....	Aug., 1919	89
114		5.00	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	Aug., 1919	89
110		5.40	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	....	July, 1920	100
113		6.20	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	....	Lost
112	Fraction	8.20	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	X	....	....
111		9.70	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	X	....	....
116	4	12.30	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	July, 1920	100
28		14.87	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	....	....	....	**
115	Creosote	16.00	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	X	....	....
27		16.98	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	X	....	....	....
25		17.27	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	....	....	....	Lost
26		18.95	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	X	....	....	....
158		3.40	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	....	Feb., 1917	59
164		6.40	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	X	....	....
160		6.90	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	....	Nov., 1921	116
159		7.00	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	X	....	....
36	Fraction	7.33	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	....	....	....	***
161		8.60	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	Nov., 1921	116
163	5	9.20	Longleaf pine	Gulfport, Miss.	March, 1912	X	....	....	....	....
162		11.50	Longleaf pine	Gulfport, Miss.	March, 1912	X	....	....	....	....
34	Creosote	11.71	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	X	....	....	....
157		14.90	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	....	X	....	....
35		16.88	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	X	....	....	....
33		18.24	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	....	....	....	Lost
108		4.60	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	X	....	....
106		7.40	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	Nov., 1921	116
102		8.80	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	X	....	....
101		9.60	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	X	....	....
107	Coal tar	10.30	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	X	....	....
104		10.50	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	....	Jan., 1923	....
105	Creosote	11.90	Longleaf pine	Gulfport, Miss.	March, 1912	....	....	....	....	Lost
103		13.80	Longleaf pine	Pensacola, Fla.	March, 1912	....	....	X	....	....
41		17.98	Loblolly pine	Pensacola, Fla.	Jan., 1911	X	....	....	....	....
43		18.00	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	X	....	....	....
44		20.50	Loblolly pine	Pensacola, Fla.	Jan., 1911	....	....	....	....	****
42		22.38	Loblolly pine	Pensacola, Fla.	Jan., 1911	X	....	....	....	....

*Lost 1921. Medium attack 1920.

**Lost 1921. Showed slight attack 1920 inspection.

***Lost 1921. Showed very severe attack 1920 inspection.

****Lost 1921. Showed medium attack 1920 inspection.

Note: Mark X shows degree of attack when specimens are not destroyed.

Specimens Nos. 49 to 52, inclusive, and Nos. 181 to 196 inclusive, placed in test untreated. Average life 1 to 2 years.

which creosote was used to which various fractions had been added; in other words, the creosotes were reinforced. The test materials were treated with creosotes as follows:

Schedule 1. The experimental test timbers are of rather large size, designed for exposure in Bay waters under as nearly service conditions as possible. Five, and in some cases six, pieces were subjected to the same treatment, one each for four different stations in the Bay, with one or two for laboratory use. There were sixteen different treatments, which were synthesized according to the following table:

1. Fraction A (210°–235° C.)
2. Fraction B (235°–315° C.)
3. Fraction C (315°–355° C.)
4. Fraction D (Residue above 355° C.)
5. Whole creosote.
6. Whole creosote + fraction A.
7. Whole creosote + fraction B.
8. Whole creosote + fraction C.
9. Whole creosote + fraction D.
10. Whole creosote — fraction A.
11. Whole creosote — fraction B.
12. Whole creosote — fraction C.
13. Whole creosote — fraction D.
14. Whole creosote — tar acids.
15. Fraction D (repeated).
16. Oil tar distillate.

These creosotes were synthesized so that the several fractions were added or subtracted in the proportions in which they occurred in the whole creosote, which were the following:

Fraction 210° C.—235° C	10%
Fraction 235° C.—315° C.	40%
Fraction 315° C.—355° C.	23%
Residue above 355° C.	27%

In view of the difficulties incident to obtaining clear-cut separations by fractional distillation, and consequently to obtaining clearly marked differences in inhibitive or destructive effects upon living organisms, it was felt that the doubling of effect gained by both adding and subtracting the required fraction in each case to the whole creosote might so increase the decisiveness of this general method as to make it yield useful results. A piece of untreated wood was attached as a bait to each of those treated and a set of eight specimens so prepared was placed in a rack. Racks containing test pieces of each of the sixteen different treatments are now in place at the following stations in the Bay: San Francisco Pier No. 7, Southern Pacific Oakland Pier, Mare Island, and Crockett. An analysis of the creosote from each of the runs has been made, as well as of that extracted from one of the test pieces after treatment. Similar extractions will be made of the creosote of each of the test pieces, as they are removed from time to time.

During 1922 under the auspices of this Committee and in cooperation with the Barrett Company, a number of pieces of pine and Douglas fir were treated with creosote prepared so as to give creosotes from which various fractions had been removed. The underlying idea of these experiments was to determine if possible whether the *absence* of one or the other of the fractions would show greater marine borer attack from which conclusions might be drawn as to the efficiency of one or the other fraction. The details of these particular tests were as follows:

> The work covered by this report had for its principal purpose the preparation of a series of creosotes from two distinct types of tar and the impregnation of yellow pine and Douglas fir sticks with these creosotes for

later immersion in San Francisco Bay with the object of learning the relative resistance of the creosotes to the attack of the *Teredo*.

Preparation of Oils

Two tars were used—
Vertical Retort Tar
Coke Oven Tar

The former was selected as representing a high acid, low naphthalene tar, and the latter as a relatively low acid, high naphthalene tar.

One hundred gallons of each were distilled by straight distillation to approximately 300° F. melting point pitch in the experimental plant still.

From the total distillate obtained from each tar, eight (8) different types of creosote were obtained and designated as follows: the letters C and V respectively indicating Coke Oven Tar and Vertical Retort Tar.

Table 1

Coke Oven Tar Distillate					Vertical Retort Tar Distillate			
Stick No.	Creosote Used	Vol. Stick (cu. ft.)	Treatment (Lbs. cu. ft.)		Stick No.	Creosote Used	Vol. Stick (cu. ft.)	Treatment (Lbs. cu.) ft.)
				PINE				
P-1		0.156	11.9		P-9		0.180	12.4
P-17	C.R.	0.221	12.3		P-25	V.R.	0.205	15.7
P-2		0.193	15.0		P-10		0.161	14.1
P-18	C.S.R.	0.187	14.5		P-26	V.S.R.	0.240	13.2
P-3		0.185	14.3		P-11		0.182	12.1
P-19	C.A.R.	0.190	13.5		P-27	V.A.R.	0.232	12.2
P-4		0.163	13.7		P-12		0.163	13.6
P-20	C.B.R.	0.244	12.7		P-28	V.B.R.	0.197	13.5
P-5		0.199	12.8		P-13		0.206	16.5
P-21	C.C.I.	0.212	12.4		P-29	V.C.I.	0.227	13.1
P-6		0.159	13.3		P-14		0.166	12.7
P-22	C.C.II.	0.225	12.3		P-30	V.C.II.	0.240	13.8
P-7		0.153	13.3		P-15		0.171	13.1
P-23	C.C.III.	0.197	12.7		P-31	V.C.III.	0.180	15.0
P-8		0.140	14.4		P-16		0.177	15.5
P-24	C.C.IV.	0.200	14.4		P-32	V.C.IV.	0.200	15.5
				FIR				
F-1	C.R.	0.208	15.0		F-9	V.R.	0.240	14.3
F-2	C.S.R.	0.165	15.1		F-10	V.S.R.	0.174	14.9
F-3	C.A.R.	0.233	12.3		F-11	V.A.R.	0.134	16.6
F-4	C.B.R.	0.151	16.3		F-12	V.B.R.	0.215	12.6
F-5	C.C.I.	0.236	15.8		F-13	V.C.I.	0.143	13.4
F-6	C.C.II.	0.161	16.3		F-14	V.C.II.	0.205	12.7
F-7	C.C.III.	0.214	19.9		F-15	V.C.III.	0.188	15.1
F-8	C.C.IV.	0.156	17.2		F-16	V.C.IV	0.168	16.3

1. ORIGINAL OR RAW CREOSOTE.—Designated C (or V)-R. This was a sample of the total distillate from the experimental plant still.
2. CREOSOTE—SOLIDS REMOVED.—Designated C (or V)-S.R.—Prepared from 1 by cooling in ice-box to about 10° C. for three days and then removing solids by whizzing.
3. CREOSOTE—ACIDS REMOVED.—Designated C (or V)-A. R.—Prepared from 1 by treating with 10-15% NaOH solution until tar acids were completely removed. The creosote was then washed free of alkali with water and salt solution.
4. CREOSOTE—BASES REMOVED.—Designated C (or V)-B. R.—Prepared from 1 by treating with 20% H_2SO_4 until tar bases were completely removed. The creosote was then washed with water and finally treated with $CaCO_3$ to neutralize any free H_2SO_4 remaining.

5-8. COMPOSITE CREOSOTES.—Designated C (or V) C-I, II, etc.—These were prepared from 1 by fractionating in 5-gallon laboratory stills using a Hempel tube about 3 inches high filled with beads. All distillate having a specific gravity below 1.000 was discarded except in the case of the Vertical Retort Tar creosote, where all distilling below 200° C. vapor temperature was discarded. The following fractions were taken:

Fraction 1, Sp. Gr. 1.000—230° C. vapor temperature.
Fraction 2—230° C.–270° C. vapor temperature.
Fraction 3—270° C.–360° C. vapor temperature.
Fraction 4—Residue above 360° C.

Four composites were then prepared, from each of which one fraction was omitted and the other three combined in the relative proportions to one another in which they existed in the original oil. The designation and composition of each of these composites was as follows:

COMPOSITE NO.	DESIGNATION	FRACTIONS
1	C (or V) C-1	1, 2, 3
2	C (or V) C-II	1, 3, 4
3	C (or V) C-III	2, 3, 4
4	C (or V) C-IV	1, 2, 4

The following tabulation gives the results of the distillations of the two tars and the relative proportions of the four fractions in the original creosote.

Tests of all the above described creosotes are given in Table 2.

TAR	VERTICAL RETORT	COKE OVEN
Per cent oil (by vol.)	59.0	47.6
To pitch (m.pt.° F.)	296	276
Fraction No. 1 (200°–230° C.)*	16.9	19.0
Fraction No. 2 (230°–270° C.)	29.1	22.5
Fraction No. 3 (270°–360° C.)	47.3	44.1
Fraction No. 4 (Residue)	6.7	14.4
Per cent tar acids in total distillate	18.7	7.7
Per cent tar bases in total distillate	4.7	5.6
Per cent naphthalene in total distillate	0.0	8.2
Per cent dry solids at 6° C. total distillate	1.1	4.3

*Sp. Gr. 1.000 in case of coke oven tar.

TIMBER.—Two-foot lengths of well-seasoned yellow pine and Douglas fir posts, approximately 4 inches in diameter, were submitted by Dr. Hermann von Schrenk. In the case of the yellow pine there were 32 sticks, which provided for the treatment of 2 with each creosote. Of the Douglas fir, there were 16 sticks, or one for each creosote.

TABLE 2

Oil	Designation	Sp. Gr. 15.5° C.	Retort Distillation—Total % to °C. 170	200	210	235	270	315	355	Sp. Gr. 38/15.5° C. 235-315° C.	Sp. Gr. 38/15.5° C. 315-355° C.
Coke Oven Tar Original	C.R.	1.086	0	0.9	2.4	14.9	38.1	56.0	80.2	1.040	1.104
Coke Oven Tar, Solids removed	C.S.R.	1.084	0	2.2	3.6	16.9	39.2	56.5	77.2	1.044	1.099
Coke Oven Tar, Acids removed	C.A.R.	1.086	0.1	2.9	3.5	7.7	37.5	56.3	80.7	1.047	1.098
Coke Oven Tar, Bases removed	C.B.R.	1.087	0	0.1	1.4	12.4	36.2	54.5	80.1	1.043	1.082
Coke Oven Tar, Comp. I Frac. 1-2-3	C.C.I.	1.070	0	0.5	1.7	21.1	49.4	76.4	96.2	1.045	1.107
Coke Oven Tar, Comp. II Frac. 1-3-4	C.C.II	1.075	0.2	1.2	1.9	8.4	23.2	39.0	72.0	1.048	1.112
Coke Oven Tar, Comp. III Frac. 2-3-4	C.C.III	1.099	0	0	0	2.4	25.5	53.4	79.8	1.053	1.108
Coke Oven Tar, Comp. IV Frac. 1-2-4	C.C.IV	1.074	0	1.0	6.5	44.2	64.0	71.0	77.3	1.034	....
Vertical Retort, Original	V.R.	1.050	0.2	1.2	2.3	16.7	40.7	62.7	85.0	1.014	1.069
Vertical Retort, Solids removed	V.S.R.	1.049	0.7	2.0	2.7	17.5	42.0	63.3	85.9	1.015	1.075
Vertical Retort, Acids removed	V.A.R.	1.042	0	0.4	1.1	8.4	35.6	64.3	86.7	1.010	1.069
Vertical Retort, Bases removed	V.B.R.	1.055	0.1	1.0	1.8	15.2	41.3	63.6	86.9	1.012	1.077
Vertical Retort Comp. I Frac. 1-2-3	V.C.I.	1.045	0	0.4	1.3	19.1	45.5	69.7	92.4	1.020	1.079
Vertical Retort Comp. II Frac. 1-3-4	V.C.II	1.068	0	1.4	2.9	11.3	27.5	55.5	84.1	1.026	1.084
Vertical Retort, Comp. III Frac. 2-3-4	V.C.III	1.065	0	0	0.1	3.9	31.0	60.3	84.1	1.021	1.081
Vertical Retort, Comp. IV Frac. 1-2-4	V.C.IV	1.039	0	1.0	5.0	49.2	72.8	82.0	87.0	1.010	....

Impregnation.—It was originally contemplated to treat both types of wood by the full cell process, but preliminary experiments indicated that this would result in a heavier and less uniform treatment than desired—12 to 15 pounds—when applied to the pine. Pine was, therefore, treated by the Rueping process, and the fir, which was much denser and closer grained, was treated by the full cell process. The general methods pursued were as follows, with slight variations to accomplish the desired treatment:

Rueping Process.—Stick was placed in large cylinder and flange bolted on. Pressure of 25 pounds applied. Creosote heated to 170°–190° F., poured into small cylinder and put under 75 pounds pressure. Creosote then allowed to run in on wood and pressure raised in 25-pound increments until desired treatment was obtained. The final pressure varied from 100 pounds to 175 pounds. Creosote was then drained off and vacuum applied for a few minutes to dry the stick.

Full Cell Process.—After placing stick in large cylinder, the flange was bolted on and a vacuum of 25 inches to 27 inches (mercury) applied. Creosote at 170°–190° F. was then admitted from upper cylinder and a pressure of 75 pounds applied to the system. This was gradually raised until the desired treatment was obtained. The final pressure varied from 100 pounds to 175 pounds. Creosote was then drained off and vacuum applied for a few minutes to dry the stick.

All sticks were carefully calipered for the determination of their volume, and weighed before and after treatment for determination of the amount of creosote put in.

On account of the rather coarse graduations of the gauge, they could not be wholly relied upon for a determination of the amount of the treatment, and in most cases this was determined by drawing off the creosote, weighing it, and returning it to the cylinder for a continuation of the treatment if a sufficient amount had not been taken up. Several of the fir sticks were given a heavier treatment than desired, and the application of a sustained vacuum failed to draw out the excess creosote.

The creosote used and the weight of treatment for each stick are given in table 1.

The time which has elapsed since the tests were started is too short to expect results from any of the methods of protection having any considerable value. All test pieces are reported by the San Francisco Committee not to have been attacked except as indicated in the table on page 149.

In view of the long service which some of the San Francisco Bay piles had given and in order to determine whether local conditions, or whether the type of creosote in these piles had been responsible for their long service, a number of sound piles taken from the Oakland Wharf of the Southern Pacific Company were redriven.

There were seven test piles driven in wharf No. 63 of the Atchison, Topeka and Santa Fe Railroad at San Diego, Cal., in 1919; four of these were from the Long Wharf treated in 1890, two were treated with a distillate creosote in 1919, and one was untreated. All of the old piles had been attacked by *Limnoria* by the end of 1922 to a depth of from ¼ inch to ½ inch.

A similar series of test piles was placed by the Northwestern Pacific Railway in their wharf at Tiburon, Cal., in 1919. None of them had been attacked after three years' exposure.

The Southern Pacific Railway drove similar piles at San Pedro in 1919, and also drove 12 piles treated in 1897 as brace piles in their wharf No. 2 at Oakland, Cal., in October, 1919. None of them had been attacked after three years' exposure.

Preservative	Date of Immersion	Date of Inspection	Condition
Williams and Francois oil, Arent Laboratory	Jan. 19, 1922	Sept. 4, 1923	Attacked by *Limnoria*
Aczol-Zinsser Co.	Jan. 19, 1922	Sept. 4, 1923	Attacked by *Limnoria*
Benzol and antimony trichloride, Arent Laboratory	Jan. 19, 1922	Sept. 4, 1923	Heavy attack by *Limnoria*
Antimony trichloride	Nov. 18, 1921	Aug. 11, 1922	Light attack by *Limnoria*
Antimony trichloride	Nov. 18, 1921	Sept. 4, 1923	Heavy attack by *Limnoria*
Paraffine	Dec. 12, 1922	Sept. 4, 1923	Attacked by *Limnoria*
Dr. Bartsch's patent paraffine and copper iodide	Dec. 12, 1922	Sept. 4, 1923	Attacked by *Limnoria*
Cooper - Case - Anderson Co., Elaterite, 1 dip	Jan. 5, 1923	Sept. 4, 1923	Attacked by *Limnoria*
Elaterite, 2 dips	Jan. 5, 1923	Sept. 4, 1923	Heavy attack by *Limnoria*
Alder wood	Jan. 5, 1923	Sept. 4, 1923	Bark mostly gone. Scattered *Limnoria* attack
San Francisco Committee Special Tests			
Arsenic	Dec., 1922	Sept. 4, 1923	Attacked by *Limnoria*
Antimony	Dec., 1922	Sept. 4, 1923	Attacked by *Limnoria*
Selenium	Dec., 1922	Sept. 4, 1923	Attacked by *Limnoria*
Mercury	Dec., 1922	Sept. 13, 1923	Attacked by *Limnoria*

The Northern Pacific installed a test series in their Pier No. 1 at Seattle, Wash., in March, 1920. This series contained three piles from the Long Wharf treated in 1890 and one treated in 1901; two Southern Pacific piles treated with 14 pounds of creosote in August, 1919; one treated by boiling under vacuum and impregnating with 14 pounds of creosote by the Pacific Creosoting Company; one treated by the steaming process and impregnated with 16 pounds of creosote by the Coleman Creosoting Company in March, 1919, and one untreated pile. In October, 1920, an inspection showed that the untreated pile had been attacked by *Bankia* and that the treated piles were still intact.

Six sections 24 inches long, cut from three unattacked piles treated in 1890, were installed by the Forest Service at Pensacola, Fla. Three sections were cut from the mud line and three from the water. The ends of the specimens were protected by zinc or copper sheathing and they were placed in the water in August, 1919. These specimens showed no attack after one year's immersion, but in January, 1924, all of them had been attacked by *Limnoria* and were penetrated to depths varying from 1/4 to 3/8 inch.

Conclusions—A study of many creosoted piles which have been attacked by shipworms and *Limnoria lignorum* shows that there are many piles with unequal penetration, and that the attack begins at the points where the penetration is the least. This emphasizes the necessity of securing uniform penetration around the entire periphery of each pile.

It is also very clear that many piles fail on account of physical damage which allows the boring organisms to obtain access to the untreated center

of the pile on account of damage to the treated shell of the pile before or after driving. It is generally impossible to prevent abrasion of the surface after the pile is driven, but damage in handling before driving can and must be avoided if the maximum life is to be obtained.

The portion of a pile which in the finished structure will be between the mud line and high water, should not be touched with a pike pole, no dogs should be driven, boom men should not be permitted to walk on the pile with caulked shoes, the pile should not be picked up with chains which will crush the fiber of the wood, nor should the surface be damaged in any other way. It should go without saying that no framing should be done below high water.

Both shipworms and *Limnoria lignorum* will seek out and attack through the smallest defects, and after the shipworms have become established and their development has proceeded beyond the larval stage, they seem to work only little less freely in creosoted than in uncreosoted timber. Even at a considerable increase in construction cost it is well worth while to see that creosoted piles are so handled that they will not be damaged.

As has been pointed out in several instances above, while coal tar creosote has been used in the treatment of piling for a great many years, it is still unknown exactly what specific qualities in the creosote are essential to give the longest service to creosoted piles. Early pile treatment in the United States was carried out with creosotes having high naphthalene contents, (such as the Norfolk piles above referred to and one of the San Francisco pile series). Treatment during the last 15 or 20 years has been conducted with heavier creosotes with lower naphthalene contents. When used by themselves the various fractions of creosote show marked differences. As pointed out in connection with the Forest Service experiments, the higher boiling or heavier fractions of the creosote seem to have the greater protective efficiency. To what extent this may be true when these fractions are present in actual creosotes is still doubtful, because as indicated in the Norfolk piles a very long service was obtained with creosote containing high percentages of low boiling fractions. Many of the analyses of creosote extracted from old piles, while interesting, afford very little evidence one way or the other, because so little is known of the nature of the creosotes used in such cases when the piles were first treated. It should also be remembered that success or failure may not always be due to the nature of the creosote, because as has already been shown, improper penetration, too little creosote per cubic foot, and variability in the timber, are probably as important factors as the quality of the creosote used.

Taking all the evidence available the following recommendation will probably give efficient protection. Treat air dried piles wherever possible. Treat these with at least 18-30 pounds of creosote per cubic foot, depending on the width of the sap ring, and very refractory wood species treat with creosote to refusal. In the treatment use a pure distillate coal tar creosote conforming to Specifications 1, 2 and 3 of the American Railway Engineering Association.

If the creosote be of the best quality, if the impregnation be thorough, and the timber be not damaged by handling or framing, there appears to be no question but that creosote impregnation is the most efficient impregnation method of protection in use at present.

CHAPTER VII

SUBSTITUTES FOR TIMBER

Timber for marine structures has many advantages not found in other materials, of which its wide distribution, comparatively light weight, ease of working and consequent low cost in place are of prime importance. When the results of the destructive effect of marine borers and fungi are taken into consideration and the high cost of replacing piles in heavy structures, where in addition to the actual cost of the work, the interference with traffic causes losses, the economy of the use of timber piles becomes less apparent, and if materials of longer life are available which at the same time can be used in salt water structures at reasonable first cost, their use may be fully justified.

Timber can be protected from marine borers and from decay sufficiently to greatly increase its life, but the cost is considerable. The cost of construction with protected timber is somewhat higher than with unprotected, and with the increasing cost of timber on account of its growing scarcity, the economic necessity for the development of other types of construction becomes of great importance. In considering the permanency of harbor structures, the question of obsolescence must not be lost sight of, and so far as experience can predict care should be taken not to use a material, at high first cost, which will have a life much longer than is desired for the entire structure.

The most promising substitutes for timber for use in structures for which long life is desired are concrete and metal. Both deteriorate from causes not thoroughly understood and therefore this deterioration can neither be accurately predicted nor entirely prevented. Both materials require much study, which can be carried on both in the field through construction and service records, and in the laboratory, the two methods being necessarily complementary.

CONCRETE

Concrete is generally considered the most promising substitute for timber, although it does deteriorate. The deterioration of mass concrete in salt water may be caused by the chemical action of the sulphates of the water on the constituents of the concrete and by the mechanical action of water, ice or debris. Reinforced concrete is subject to attack by the same agencies, and in addition it may be destroyed by the corrosion of the reinforcement and the disruption of the concrete by the consequent expansion of the products of corrosion.

It seems certain that the rate of deterioration of concrete, all other factors being the same, is in proportion to the permeability and porosity. Good concrete seldom deteriorates seriously below low water, and most of the attack on both plain and reinforced concrete occurs above low water. Reinforcing rods do not generally show serious corrosion in the portion of the structure constantly immersed, but the corrosion and consequent spalling and

SERVICE RECORDS OF CONCRETE STRUCTURES IN FOREIGN WATERS

Location	Structure	Date Built	Construction Data	Condition
Newcastle, Eng....	Breakwaters	1855–95	Air seasoned, granite faced blocks, lime Portland and Roman cement used	Lime blocks in bad condition. Portland some good, some bad. Roman all good
Chatham, Eng.....	Dock walls	1870	1-12 gravel	Considerable deterioration
Auckland, N. Z...	Dry dock	1878	Mass concrete with binding medium ½ cement ½ volcanic scoria	Good in 1915
Dublin, Ireland....	Poolbeg Lighthouse	1880	140 ton air seasoned blocks	Good
Newcastle, Eng....	High Dock	1880	Mass concrete	Disintegrated
Colombo, Ceylon...	Breakwater	1875–85	10-30 ton blocks air seasoned 3 months	Good
Southampton, Eng.	*North Pier	1878–83	Mass concrete	Disintegrated
Liverpool, Eng....	Hornby Dock	1882	Mass concrete	Good in 1914
Peterhead, Eng....	Breakwater	1886	Cyclopean mass concrete blocks 1-6 mixture granite faced	Good
Scarborough, Eng..	Sea wall, Royal Albert Drive	1886	Mass concrete	Disintegrated
Scarborough, Eng..	Sea wall, Royal Albert Drive	1886	Blocks air seasoned	Good
Auckland, N. Z....	Calliope Dry Dock	1886	Mass concrete with scoria	Good
Belfast, Ireland....	Alexandra Dock	1885–89	1-2-2½ and 1-2-3½ with facing 1-1-3	Some disintegration
Gothenburg, Sweden.	Masthuggett Quay	1888	Tremie concrete	Not good
Newcastle, Eng....	Smith's Dock	1889	Mass Cyclopean Concrete	Disintegrated
River Tyne, Eng..	†Graving Dock	1892	....	Bad
Southampton, Eng.	Piers River Itchin	1899	1-4 mix reinforced	Good
Ymuiden, Holland..	Groin	1903	Reinforced	Reinforcing corroded and concrete soft
Southampton, Eng.	Piers	1902–05	Reinforced 1-4 mixture	Bad
Uddevala, Sweden.	Platform 0.6 in. thick	1905	Poured under water 1-4-6 mixture	Some abrasion but generally good
Liverpool, Eng....	Princes Dock	1905	Piles reinforcing 1½" cover	Slight deterioration
Gravesend, Eng...	Henley's Jetty	1905	Piles and Deck 1-2-4 mixture	Deteriorated
Gravesend, Eng...	Swanscombe Jetty	1906	Columns built of seasoned blocks and reinforced deck	Columns good—dock deteriorated
Liverpool, Eng....	Brocklebank Dock	1907	Piles 1½" cover on rods	Slight deterioration
Gravesend, Eng....	Thameshaven Jetty	1907	Columns cast in water 1-1½-3 mixture, Deck 1-2-4	Slight deterioration in columns. Concrete soft in deck
Aden, Arabia......	Piles	1907	1½" cover on reinforcing	Good
Island of Urk, Holland	Seawall	1907	1 cement—½ trass, 3 sand, 4½ stone, mixture	Good
Halifax, N. S......	Piers	1907-14	Mass concrete 1-3-3 mix	Bad
Newcastle, Eng....	Tyne Dock	1908	Reinforced piles and deck	Some rust streaks
Vleiland, Holland..	Seawall	1909	0.20 m. x 0.12 m.-335 piles 2 per cent reinforcing — mixture, 1 cement ½ trass, 3 sand, 4½ gravel	Good
Fleetwood, Eng....	Fish Dock	1909–11	Piles and deck 1½" cover	Piles good. Deck rusted

* The disintegration of these walls as reported by G. E. B. Coulcher in the

splitting of the concrete takes place above low water and frequently above high water. Deterioration of well built reinforced concrete does not often indicate its presence by rust stains in much less than 10 years.

Service records (page 152) based on inspections made since 1918, except as otherwise noted, have been obtained from the Reports of the Institution of Civil Engineers, 1920, 1921 and 1922, the papers presented before the International Navigation Congresses of 1908, 1912 and 1923, and other foreign sources.

It is impracticable to give complete data of mixtures and methods of constructions used, within the limits of this report, but these structures are described in detail in reports noted in the appended bibliography.

Test blocks 0.20 m. x 0.20 m. x 1.0 m. made with the mixtures indicated below were placed at half tide at Ymuiden, Holland, in 1912;

1½ cement	½ trass	3 sand	5 gravel
2 cement	1 trass	3 sand	6 gravel
2 cement	2 trass	3 sand	7 gravel

Reinforcing rods were placed 1 cm., 2 cm., and 10 cm. from the surface. In 1914 after 2 years' immersion there was no sign of disintegration, and in 1922 there was no sign of chemical action on the concrete, but rust appeared over the rods with 1 cm. and 2 cm. cover.

Records of structures built since 1911 have been omitted because it does not seem probable that much indication of probable service life can be obtained from structures under 10 years old. From a study of the table it will be seen that out of 30 structures reported, 17 show deterioration, and

---

Proceedings Inst. C. E. 1913, Vol. CXCV, had extended to a depth of 3 or 4 feet after 30 to 35 years service. The interior of the walls was hard and specimens were analyzed from this hard concrete and from the disintegrated concrete on the original face. Specimen No. 1 was cut from the hard concrete in the center of the wall and No. 2 from the disintegrated concrete at the original face. Analyses were as follows:

	SPECIMEN NO. 1	SPECIMEN NO. 2
Lime	58.85%	18.80%
Magnesium	4.94%	23.89%
Sulphuric anhydride	3.05%	12.95%

† This dock was found when it was put in service not to be watertight. In 1893 signs of failure began to appear, and from that time on frequent repairs were made by cutting out soft concrete and replacing it. In 1909 it was found that the rings holding the heelposts of the gates had risen 3¼ inches on one side and 2⅝ inches on the other on account of the "growing" of the wall. The rings were reset, but in 1913 this operation had to be repeated, and again in 1916. The walls were originally 26 feet 3 inches high above sill; the depth of water at high water was 21 feet 3 inches with an extreme range of tides of 14 feet 6 inches. The total increase in the height of the west wall beween February, 1892, and September, 1916, was 7⅝ inches, and of the east wall 5¼ inches. Both walls were badly cracked and bulged, but the sill masonry built of the same materials and constantly immersed had not changed in any way. The valve chamber was in the west wall, and the water had better access to the center of the wall than was the case in the east wall, which fact probably accounts for the greater deterioration of the west wall.

The cement was carefully tested and was the best to be obtained at the time. The mixture in the dock walls was one part cement, 1½ parts sand and 4½ parts gravel, and in accordance with the standard practice of that time was mixed drier than is now considered desirable. It was well tamped.

of the 13 in which deterioration is not reported 4 contained trass or other siliceous admixture, and one was built with granite faced blocks.

The records of such American structures as have been secured, with as full a description of the methods and materials of construction as could be obtained, have been included in the reports on the various harbors in another section of this report. These reports include not only structures over 10 years old but those of later date for which records of construction could be obtained, so that future investigators would have this information available when studying their condition.

A description of those structures will be found in the reports on the following harbors:

Maine Coast	4 structures
Portsmouth, N. H., to Provincetown, Mass.	2 structures
Boston Harbor	6 structures
Buzzards and Narragansett Bays	3 structures
Long Island Sound	1 structure
Norfolk Harbor	9 structures
Beaufort, N. C., Harbor & Cape Fear River	1 series of structures
Savannah & Brunswick	1 structure
East Coast of Florida	5 structures
Key West, Fla.	10 structures
Key West to Mississippi River	2 structures
San Diego and Los Angeles	6 structures
San Francisco	Summary of many structures
Puget Sound	7 structures
Guantanamo, Cuba	1 structure
Dominican Rep.	4 structures
Pearl Harbor, H. I.	5 structures
Tutuila, Samoa	2 structures

Seventy-four structures are listed, of which 39 were reported to be in all stages of deterioration from slight to completely destroyed. Of the total number of structures listed, 24 have been built since 1915 and 3 of the older ones are built on cylinders encased in steel shells which are still in good condition.

For various reasons it has been impossible to collect a complete record of concrete structures, but it is thought that those records obtained are fairly representative of existing structures. Structures exposed to unusual conditions such as those at coast resorts subject to the wave action of the open sea have not been included in the study, because the deterioration of such structures is frequently influenced by the use of designs which did not adequately provide for the heavy shocks to which such structures are exposed, and it seemed impossible to separate failures caused by improper design and those for which other causes were responsible.

There are two characteristic types of failure of plain concrete, one a disintegration apparently caused by the expansion within the concrete of a great number of small particles giving an explosive effect, and the other by the disintegration of the binding medium and its change into a slimy, semifluid substance. In the first class may be included the effect of the formation of ice in porous concrete or the replacement of one chemical constituent by another occupying a greater volume. The effect on the concrete is simi-

lar in either case. The action in the second class is caused by the replacement of a necessary cementing constituent by a soluble compound which has no cementing value.

Generally the available evidence seems to indicate that the rapidity of chemical deterioration is roughly proportional to the permeability of the concrete but some structures built with lean mixtures and the consequently comparatively porous concrete are reported where the service has been satisfactory. Such concrete is subject to disintegration by ice in the colder latitudes, but the cases where it has a good service record in warmer waters seem to indicate clearly that some binding media resist chemical attack, even though the water have easy access to the interior of the mass.

In concrete of maximum practicable density chemical disintegration is slow and mechanical destruction by ice expansion almost negligible. The results of the studies of the Structural Materials Laboratory of the Lewis Institute supported by the Portland Cement Association furnish extremely valuable information as to the proper methods of mixing and placing concrete to secure maximum density. They have probably done more to show how to build resistant concrete with Portland cement than any work previously recorded, but it does not seem that density alone can prevent disintegration. Very little work leading to the development of a binding medium which will not disintegrate under the attack of sulphate bearing water has been done in the United States.

Roman cement has been proven very durable by centuries of use. This cement was a mixture of lime and pozzuolana, a volcanic product consisting principally of silica with the necessary chemical characteristics so that it would combine with the lime in such a way as to form a cement which was stable in sea water. The ancient masonry was not all successful, and although many of the structures built in the days of Imperial Rome in salt water are still standing, the writings of Vitruvius show that many failures occurred.

After many experiments John Smeaton used a similar material for the cement in the Eddystone Lighthouse, which stood for over 100 years. But neither in the case of the Roman cement nor in that of Smeaton was the chemistry of the compound known.

In France, Vicat began the study of cements for use in sea water early in the Nineteenth Century. His work continued about 40 years and was the first, and one of the most thorough scientific studies ever made. Vicat discovered that a cement which would resist the chemical attack of sea water must be so constituted that when it set the lime, released in the process of setting, would all be combined with silica and alumina.

Many investigators on the continent of Europe followed Vicat, among whom were Le Chatlier, Candlot and Feret in France, Michaelis and Burkhartz in Germany, van Kuffler in Holland, Poulsen in Denmark, Jeanneret in Switzerland, Luiggi in Italy, de Castro in Spain, and many others. In general the results of their laboratory and field studies corroborated those of Vicat and by the use of the microscope they were able to do their work more thoroughly than had Vicat. In the United States, Day, Wright, and Rankin at the Geophysical Laboratory of the Carnegie Institution of Washington confirmed the results of European experimenters and developed the use of the petrographic microscope much further than had previously been done. They developed the binary and ternary systems and made possible the later work of Bates and others at the Bureau of Standards.

Practically all these investigators agree that the most active disintegrating element in sea water is magnesium sulphate; that ordinary Portland cement after setting leaves a residue of from 15 per cent to 30 per cent of free lime; that the magnesium sulphate combines with the free lime in the concrete and frequently leaves a deposit of calcium sulphate crystals which occupy roughly 1.4 times the volume occupied by the lime, resulting in the explosive effect above mentioned. That if there be even a slight movement of the water in the body of the structure after the removal of the free lime the tricalcium silicate which is the most quickly formed product in the setting of the concrete is broken down, and that this process once commenced continues until the concrete is reduced to a disintegrated mass of sand and other aggregate.

One method of preventing this disintegration is by adding to the cement a finely ground silica, having the necessary qualities, and in a proper quantity, such that, on setting, the silica and the lime will form compounds insoluble in sulphate bearing waters. The silicious materials which have been used for this purpose are pozzuolana from Italy, Santorin earth from Greece, trass from Germany, tuff from California, all of volcanic origin; diatomaceous earth from Denmark, and some blast furnace slags. Ordinary silica sand or the product of disintegrated or ground granite does not generally contain an appreciable quantlty of soluble silica which will combine with the lime, but some burnt clays do contain it and can therefore be used like pozzuolana.

The addition of silica to Portland cement or to lime not only results in the formation of compounds little affected by the attack of sulphates, but is also of considerable value in making the concrete more impervious. This action is supposed to be caused by the colloidal properties of silica which close the pores of the concrete. The more impervious concrete obtained by the use of the silica admixture resists much better the disintegration caused by the formation of ice crystals within the concrete, than does the concrete in which silica is not used. In making this addition the amount of silica to be added should be slightly in excess of the amount of soluble silica required to combine with the free lime released by the cement in setting, and the two materials should be ground together.

The use of the so-called "blended cements" (cements to which silica has been added) in salt water has been very general in all the Mediterranean countries, and excellent results have been obtained since the days of Rome. In Germany and other countries of northern Europe this material is recognized as the most suitable binding medium for salt water structures, and a cement made from Portland cement and diatomaceous earth is now being manufactured for this purpose by the Aalborg Company in Denmark.

The Engineering Standards Committee in England in 1923 adopted a specification for a blast furnace slag cement which is being used for the same purpose. In the United States the only recorded use of a "blended cement" containing silica having the proper qualities was in the construction of the Los Angeles Aqueduct, where silica was used as an economy and not because of its ability to resist attack by sulphates. This work is in excellent condition, while concrete in the Elephant Butte and Arrowrock Dams of the Reclamation Service is not so good. In these two latter structures ground granite was used for the silicious material, while in the former volcanic tuff was used.

The "blended cements" have generally given quite as high short time strength tests as the best Portlands, though the difference is not great. Mass concrete harbor structures do not as a rule need high strength, and concrete made of lime, soluble silica and proper aggregates, will generally have sufficient strength. In any case resistance to sulphate attack in such structures is of more importance than great strength. It is stated by some of the European engineers and investigators that the addition of the correct amount of soluble silica to Portland cement results in greater strength. It is seldom that these admixtures have been made under proper chemical control.

Another binding mixture probably invented by Colonel Henry Spackman, who described it in 1910, and later developed in France principally by M. Jules Bied, which secures practically insoluble compounds, is known as "Alca cement," "Ciment fondu," or "Ciment electrique." In this cement the cementing compounds are calcium aluminates instead of calcium silicates as in the case of Portland cements. The alumina and calcium are fused in a blast furnace or electric furnace instead of being clinkered in a kiln. The manufacture is more expensive than that of Portland, the cost at the present time (1923) being about three times as much in France as that of Portland.

"Ciment fondu" has desirable qualities other than its ability to resist sulphate attack. It hardens very quickly and sets in about 5 hours. Its strength at the end of three days is equal to that of the best Portland at the end of 28 days, and increased strength is maintained so far as is shown by available tests covering a period of 8 years. The long time tests of this alumina cement do not show the decided fall in strength between the sixth and tenth years which is characteristic of Portland.

This cement is not as yet available in the markets of the United States, except by importation, and it is probable that further study of its manufacture will make it possible to reduce its cost and encourage its manufacture in the United States. On account of its resistance to sulphate bearing water, either sea water or the alkali water of the West, its use should make possible the construction of much more enduring structures than those built with Portland cement. On account of its quick hardening and high initial strength it is very useful for pavement and similar work, and its use in building work will make possible lighter sections and less form material.

It is possible with the best Portland cement to build structures with a very considerable life, but a rich mixture must be used and the greatest precaution taken to secure maximum density by a very careful proportioning of materials, including gauging water. All these precautions add to the cost of construction, while a "blended cement" should be slightly cheaper than Portland, and such extreme and expensive precautions in proportioning and handling as is necessary with Portland cement should not be required with a binding medium which is not so readily attacked by sulphates. The uncertainties of the human equation on account of the use of ignorant labor and the difficulty of control will also be reduced.

Both the "blended cement" and the "Ciment fondu" require study to determine the best mixtures and methods of handling, and since with "Ciment fondu" a considerable saving in the time of seasoning is possible, new specifications will have to be developed to take advantage of all possibilities of the new material. Piles have been successfully driven in France three days after pouring, and specifications will have to be so drawn as to permit such economies.

Reinforced concrete, in addition to the deterioration of the concrete from chemical or mechanical causes, also suffers from the corrosion of the reinforcing. The products of corrosion expand and cause spalling or splitting of the concrete, and this in turn accelerates the corrosion. This corrosion seldom shows below low water, and is generally most active at about high water, though the action is frequently rapid in the members of the deck of a wharf well above high water.

The causes of this corrosion are not well understood, but there is little question that the construction of an impervious concrete will greatly retard if not entirely stop it. There seems to be little question that the minimum cover with Portland cement concrete over the reinforcing should not be less than two inches and many engineers think three inches still more desirable. In the case of piles, a 3-inch cover places the reinforcing so close to the neutral axis that the amount of reinforcing and consequently the cost of the piles and the difficulty of handling them will be increased.

In order to render the concrete less pervious, structures have been painted with tar, pitch, or asphalt, and some good seems to have resulted, but such a coating requires renewal from time to time and adds to the cost of both construction and maintenance. Another method of protection for piles by impregnation with asphalt has been tried in Los Angeles and will be found described in the report on that harbor. The use of this method is of too recent date to have furnished service records of value.

Galvanizing or otherwise protecting reinforcement is practised to some extent, but it is very difficult to secure a coating which is an efficient protection against corrosion and does not at the same time lessen the strength of the bond between the steel and concrete. The use of non-corrosive alloy steel may help to solve this problem, but such steels must have long time tests to determine their efficiency, and their cost will be higher than that of carbon steel. A large number of such tests are now under way under the direction of the Institute of Civil Engineers of Great Britain.

It is recognized that there is greater shrinkage in rich concrete than in lean, and experiments at the University of Illinois show that in heavily reinforced units such as piles, the shrinkage is sufficient to cause minute cracks to appear in the concrete. For this reason an extremely rich mixture is likely to give as easy or easier access for the salt water to the steel than a leaner and more permeable concrete which does not have so much shrinkage. A series of experiments on this subject are now under way at Leland Stanford Jr. University. It is therefore apparent that any improvement in the cement which will render the concrete less permeable is of even more importance to reinforced than to plain concrete, because the richer mixtures with higher shrinkage will be less necessary.

METAL STRUCTURES

Three metals, cast iron, wrought iron, and steel, have been quite extensively used for harbor structures, and it appears from a study of the records that the durability of these materials has not been generally appreciated. For this reason it is probable that the design of such structures has not received as much study as has that of the more generally used materials, and that it may be so improved as to lessen the injury to the structure by corrosion and shock and to reduce the cost.

Cast Iron

This material, generally used in the form of columns or piles with either cast iron, wrought iron or steel braces, deteriorates very slowly in salt water. There is a gradual change in the structure of the iron which results in the shape and appearance of the member being little changed while the iron is replaced by graphite. This action is generally so slow that the structure would not be seriously weakened for at least 100 years and probably not for twice that time. The older and more impure "white" cast iron resists this change better than does the better grades of gray iron. Cast iron high in silicon resists corrosion to a large extent, but is brittle and too hard to machine easily. Mr. J. Vipond Davies states (Eng. Found. Pub. No. 6, p. 39, Feb. 23, 1923) that "graphitic corrosion is probably an electrochemical reaction set up within the substance." Cast iron is open to another and more serious objection. It is comparatively low in strength, brittle and therefore easily broken by shock.

The record of structures in the table, page 160, seems more satisfactory than that of many structures built of materials much more commonly used. The reports of "condition" are based on inspections made since 1918, except as otherwise noted.

Wharves at Ft. McRea, Fla., and Ft. Scriven, Ga., are reported as old wharves, but exact date of construction unknown. The wharf at Ft. McRea was in poor condition in 1919, and that at Ft. Scriven good in the same year.

In several of these structures where wrought iron or steel braces were used it has been necessary to replace the bracing several times, but this can be done without interference with the traffic on the pier and therefore is not so serious as the replacement of piles. There is, of course, a limit to the practicable length of cast iron piles and columns which makes their use impossible in some locations.

It appears from the reports received that the breakage on account of the brittleness of the iron can be greatly reduced by filling the pile or column with concrete, even though the concrete itself have low strength.

So far as obtainable records show, cast steel and "semi-steel" have not been used for such structures, and it is entirely possible that they might resist corrosion and be stronger than cast iron.

Wrought Iron and Steel

These materials have been used in the form of solid round piles, hollow piles, rolled sections of other shapes, braces, or as forms or casings for concrete cylinders or piers where the greater part of the strength is furnished by the concrete. From the standpoint of corrosion alone the round piles are, of course, the most desirable shape because of the smaller area exposed, but bracing is more difficult than with other shapes.

The table on page 161 in which the reports on "Condition" are based on inspections made since 1918 except as otherwise noted, shows the service record of structures for which definite data could be obtained.

A comparison of the tabulations of the concrete, cast iron and wrought iron and steel shows 9 concrete structures over 40 years old, of which 5 are said to be in good condition, 10 cast iron structures of which 8 are in good condition, and 5 wrought iron all more or less corroded but still in service.

Of structures between 20 and 40 years old, there are 25 concrete structures of which 8 have shown practically no deterioration; 7 cast iron, 4 of

Service Record of Cast Iron Structures

Location	Structure	Date Built	Kind of Members	Condition
Fleetwood, England	Harbor Pier	1840	Plates and casings	Good
Gravesend, England	Royal Terrace Pier	1844	Columns	Good
Dublin, Ireland	Custom House Quay	1847	Piles	Good
Thameshaven, England	Mucking Lighthouse	1851	Columns	Good
Wellington, New Zealand	Queens Wharf	1865	Piles	Removed 1915. Good condition except for small amount graphite
Liverpool, England	New Brighton Pier	Before 1870	Piles	Good
San Francisco Bay	Alcatraz Island Pier, No. 1	1870	145 piles	65 broken by ships prior to 1922. Fair condition
Auckland, New Zealand	Bean Rock Lighthouse	1870	Columns	Good
Fleetwood, England	Wyre Lighthouse	1872	Columns	Good
Holyhead, England	Fish Jetty	1878	Piles and columns	Good—¼" graphite in spots
San Francisco Bay	Wharf, Ft. McDowell	1888	124 piles	2 replaced to 1922
Fort Monroe, Va	Main Wharf	1889	331 screw piles and columns concrete filled	Few replaced account injury. Good
San Francisco Bay	Presidio Wharf	1890	122 piles	Needs repair
San Francisco Bay	Ft. Baker, Q. M. Wharf	1891	54 piles	3 replaced to 1922. Good
Thameshaven, England	Southend Pier	1894	Columns	Good
Ft. Caswell, N. C	Q. M. Wharf	1900	Piles	Good
San Francisco Bay	Ft. McDowell—West Wharf	1903	Piles	Good
Ft. Moultrie, S. C	Wharf	1903	Piles	Good
Ft. Monroe, Va	Mine Wharf	1905-06	Piles	Good
Ft. Barrancas, Fla	Q. M. Wharf	1911	Piles	Good

Service Record of Wrought Iron and Steel Structures

Location	Structure	Date Built	Members	Condition
Thameshaven, Eng.	Mucking Lighthouse	1851	W. I. braces	Rusted. 25 per cent of section gone
Florida Reefs	Lighthouse	1852	W. I. piles and bracing	Good
Madras, India		1872	8" W. I. piles	Diameter reduced to 7", 1921
Aden, Arabia		1875	4" W. I. screw piles	Pitted ⅛" to ½" in 1908
Key West, Fla.	Naval Pier A	1879	W. I. piles	~~Serviceable~~ in 1911. Badly rusted above H. W.
San Francisco Bay	Pier 4—Ft. Mason	1886	10" W. I. piles	Poor
Karachi, India	Berth 7	1890	Steel piles and braces	22 per cent of section lost by corrosion
Lamberts Point, Va.	N. & W. R. R. Pier No. 2	1892	12" diameter, ½" thick, W. I. columns on C. I. base	Good
Puerto Plata, Santo Domingo		1895	½" steel cylinder, 4' diameter, concrete filled	Metal practically destroyed above H. W.
San Francisco Bay	Lighthouse Depot, Goat Island	1897	12" lap weld piles	Heavy corrosion above H. W.
Lamberts Point, Va.	N. & W. R. R. Pier	1898	Concrete filled steel cylinder	10 per cent metal lost by corrosion
Key West, Fla.	Naval Pier	1898	6" steel piles	Piles good but bracing bad and cased in concrete, 1914
Tutuila, Samoa	Naval Pier	1899-1900	6" and 8" steel piles	Good
Secondee, Sierra Leone	Jetty No. 1	1899	W. I. piles	Good
Chatham, Eng.	Dockyard	1899	Steel piles	Some rust above H. W. Good below
Lamberts Point, Va.	N. & W. R. R. Pier No. 3	1901	Concrete filled steel cylinder	1/32" loss from corrosion
San Francisco Bay	Q. M. Wharf, Ft. McDowell	1903	Steel piles	Good
Ft. Dade, Fla.	Q. M. Wharf	....	Iron piles	Good 1919. Destroyed by storm, 1921
Secondee, Sierra Leone	Jetty No. 2	1906	Steel piles	Good
Lagos, Nigeria	Apapa Wharf	1907	6" W. I. piles	Good
La Boca, Canal Zone	French Wharf	1908	Concrete filled steel cylinder	Cylinders destroyed. Concrete destroyed by borers
Sierra Leone	Jetty No. 2	1907	Steel piles	Good
Sierra Leone	Jetty No. 3	1908	Steel piles	Good
Hong Kong (Kowloon)	Wharf Ocean S. S. Co.	1907-09	H. sec. rolled steel piles	Badly weakened, 1915, and encased in concrete
Lamberts Point, Va.	N. & W. R. R. Pier	1913	Concrete filled steel cylinders	Good
Singapore		1913	Concrete filled W. I. cylinders	Good

which are good and 3 have had minor replacements; 12 wrought iron and steel of which 3 are good and all but one of the other 9 show only a relatively small amount of corrosion.

The quality of concrete being made at present is undoubtedly much better than that made 40 or even 20 years ago, while wrought iron has practically disappeared from the market, and ordinary steel made at present probably does not resist corrosion any better if as well as that made 30 years ago. But the durability of both concrete and steel can undoubtedly be greatly increased, the former by the use of a better binding medium with a somewhat lower cost, and the latter by the use of alloys such as chromium and copper —probably with a somewhat higher cost.

CONCLUSIONS

1. On account of the increasing price and growing scarcity of timber and the fact that the areas subject to attack by marine borers seem to be increasing, it seems that piles used for the substructures of all wharves where traffic interruptions would be expensive should be protected from borers and decay.

2. In those harbors where marine borers are known to be active or where water conditions are favorable to their growth all timber piles should be protected.

3. The cost of protection is so high and the uncertainty of results so great that for those structures where long life is desired careful consideration should be given to the use of substitutes.

4. Cast iron supports, where conditions are suitable for their use, will probably give longer service than any other material at present available.

5. Wrought iron structures have an excellent record, and if this material could be obtained at reasonable cost, structures built in locations suitable for its use and not for cast iron would probably give longer service than any other available material.

6. Some concrete structures have given excellent service for many years. It is a more flexible material from a construction standpoint than metal, and therefore more desirable. It cannot be considered a uniformly permanent material at present, though it is probable that further study of the binding media will result in much longer life for structures built of concrete.

7. Steel structures have as good a record as concrete but are generally more expensive. If the corrosion of steel can be prevented by the use of alloys or by any other economical method, there are many locations where it would prove the most desirable construction material, unless concrete can be so improved as to give a lower equated cost per year.

CHAPTER VIII

SUMMARY OF CONSTRUCTION MATERIALS

The engineer, in selecting materials for structures to be erected in sea water, must be governed in part by the life required for the structure, the character of the structure and the traffic for which it is built, the materials available in the local markets and their cost, and the funds available for construction. The preceding sections of the report give detailed information regarding the record of various materials and means of protection, and it is thought that a summary will be useful.

1. For temporary structures in harbors where borer attack is comparatively light, unprotected timber offers the most economical material, and in harbors where the attack is heavy and there is a substantial period of inactivity, temporary structures of unprotected timber may be built with safety if they are constructed at about the close of the annual period of activity of the borers and are not required to carry maximum loads more than a few months after the beginning of the next period of activity.

2. The service records of turpentine wood, manbarklak, malabayabas and mancono are promising, and where their cost is not excessive a comparatively long-lived and economical structure will probably be obtained by their use.

3. For structures where a somewhat longer life than is given by unprotected timber is required, and where, for economic or other reasons, relative permanency is not desired, unbarked piles may be used, care being taken to see that the bark is tight and that knots and blazes are covered with metal capable of resisting corrosion for the probable life of the timber. In tropical waters where palmetto is available a similar result may be obtained by the use of this timber.

The life of timber in heavily infested harbors may also be prolonged for one or two seasons by sheathing square piles with creosoted boards securely nailed, or by the use of brush treatments with creosotes or carbolineums or other pile coatings whose effectiveness has been demonstrated by tests. Such protection, if carefully given, can be depended on to carry a structure, located in a zone of heavy attack, through at least one period of activity.

4. Next in the scale of protection will be found "Pile Armors" of the type of the Perfection Pile, though the difficulty in placing timber so protected without damage to the armor is considerable. The life to be expected from the use of the Moran Process is not yet proven by service, but it promises to be more durable than several other methods of a similar type.

5. While the service records of structures protected by "Scupper Nailing" are comparatively few in number, they are promising, and where labor costs do not make this method too expensive it is worthy of consideration. Nails should not be spaced over one-half inch center to center, and should be about one inch in length.

6. Impregnation with creosote seems to give economical and efficient protection in the cooler waters when the structures are well built and the

construction of heavy structures with permanent decks, or those supporting important buildings where replacements would cause heavy traffic losses, and where such structures are located in warm and heavily infested waters, it will be found economical to protect creosoted piles from attack.

7. Copper sheathing and vitrified pipe casings will give very long life if unbroken, but this condition can only be met in comparatively few locations. Maximum life of a structure so protected will not be obtained unless the timber above high water is protected from decay.

8. Properly built concrete casings may be expected to give fair protection, especially if the concrete be dense. The use of the cement gun is a good method of securing this result.

9. The most efficient means of protecting wooden piles, which is also one of comparatively high cost, is by the use of cast iron casings. The space between the iron and timber should be filled with concrete, the pile should be covered from a point below the possibility of scour to a point slightly above high water and the timber should be protected from decay above high water, since a life of from 50 to 100 years may be expected from the iron.

10. The service given by structures of plain and reinforced concrete shows great variations. When well built with good materials they are much more durable than timber structures. The durability of the binding media at present in general use is questionable and can be much improved.

11. The durability of wrought iron structures as shown by the records is such as to justify the careful consideration of this material wherever it can be obtained. Cast iron structures have even a better record, and more study of their design would probably result in improvement in that respect. Where conditions are suitable for the use of this material it is probable that cast iron structures properly designed and constructed will have longer life than those built of any other material now used for the purpose.

These conclusions are based on the records at present available, and are not intended to predict the more efficient methods of timber protection which will, it is expected, be developed by studies of the Chemical Warfare Service and others, now in progress, the improvements in cement which the studies of the Committee show to be possible, or the improvement in the methods of preventing the corrosion of metals which is receiving much study.

CHAPTER IX

PROGRESS REPORT OF THE CHEMICAL WARFARE SERVICE

Since the personnel of the Chemical Warfare Service was experienced in toxicity studies and the information already in their hands was of great value, it was thought that this organization was especially well fitted to make an investigation for the purpose of developing new or improving old methods of protection for wooden structures from the attack of marine borers. The officers of this Service were very willing to undertake such an investigation, and as their own appropriations were inadequate and unavailable for such use, the Committee was able to arrange for the appropriation of sufficient funds by the Department of Commerce, the Bureau of Yards and Docks of the Navy Department, and the Quartermaster Corps of the Army.

The program for the investigation was prepared by the scientific staff of the Chemical Warfare Service, with the advice and assistance of several members of the Committee and its Director. This program provided for a study of methods for improving the protection of new timber structures, and for the development of methods of protection for existing structures attacked or threatened with an attack by marine borers.

The work was commenced at the Edgewood Arsenal in January, 1923, and by the beginning of the season of activity the biological studies were commenced at the laboratory of the Bureau of Fisheries of the Department of Commerce at Beaufort, N. C., which Bureau has actively cooperated in the investigations. This study was closely allied with the study of anti-fouling paints already under way under the supervision of Dr. A. W. Bray, whose assistance and advice was made available by the Bureau of Construction and Repair of the Navy.

The progress report of the Chemical Warfare Service which follows shows that great progress has been made in both phases of the investigation, and by the discovery of many previously unknown facts a valuable foundation has been laid for the studies which will be prosecuted during the coming year. It is thought that after another season's study some definite recommendations can be made for the improvement of the materials used for impregnation, and it is hoped that a method for the protection of existing structures may be developed. The Chemical Warfare Service and the individual scientists can be congratulated on the progress which has been made.

PROGRESS REPORT

Table of Contents

PROGRESS REPORT ON THE MARINE PILING INVESTIGATION

January 8, 1924

By H. W. Walker

ABSTRACT

Marine borers, mainly *Limnoria lignorum,* and shipworms, cause immense economic loss by their destruction of wooden marine structures. While this fact has been known for centuries, it was forcibly brought to the attention of the American public by the recent invasion of San Francisco bay where property amounting to millions of dollars was destroyed by these pests and the possibility of the recurrence of such an attack at a new location constitutes an ever present menace so long as untreated timber is used, or until definite means for the prevention of such an attack can be found.

The Chemical Warfare Service started preliminary work on this problem in January, 1923, and the results of this work to date are included in the following report and its appendices.

A large number of compounds were examined for their specific toxicity effects and a total of eleven compounds has been found which are definitely toxic to these organisms. Several chemical warfare compounds are included in this list, in fact, the best all around specific toxic found was chlorvinyl arsenious oxide, a modification of the well known war gas "Lewisite."

Preliminary work was started on the protection of existing structures and definite plans have been suggested for the carrying out of this phase of the investigation.

Several hundred test pieces, impregnated in various ways, were exposed to marine borer attack in the harbor at Beaufort, N. C., and valuable preliminary data have been secured. In every case the impregnated pieces gave better protection than unimpregnated control pieces, and in the majority of cases there was no attack at all on the treated pieces after from three to five months' exposure.

The determination of the most suitable materials for impregnation will ultimately depend on the economy of the material and the cost of impregnation, and additional work is essential before such materials can be definitely selected.

The conclusions drawn in this report are merely tentative as this is essentially a progress report; further investigations must be made before permanent conclusions can be drawn.

PROGRESS REPORT ON THE MARINE PILING INVESTIGATION

January 8, 1924

I. INTRODUCTION

The purpose of this investigation is the protection of wooden structures in sea water against the attack of marine boring organisms. Preliminary work on the problem was started in January, 1923. The present paper, which is essentially a progress report, describes the work of the Chemical Warfare Service on this problem since that time. Only tentative conclusions have been reached as the work has not been completed.

The problem natuarlly divides itself into two phases: the preservation of structures already in place, and the treatment of timber for new structures in order to prevent destruction.

The main types of marine borers against which protection is needed are the crustacean (*Limnoria*) and the molluscan (*Teredo* and *Bankia*) borers.

The research was conducted along three lines:

1. General:

Under this head are the toxicological and physiological tests made during the summer of 1923 at Beaufort, N. C.

2. Protection of Existing Structures:

Investigations were made of the effects of chlorine generated by electrolysis of sea water on shipworms in wood blocks, and the possibility of the use of small pieces of copper imbedded on the surface of the piles.

3. Protection of New Structures:

Sections of railroad ties, 12 inches long by approximately 3 inches square, were impregnated with various toxics at Edgewood Arsenal and exposed for actual service tests at the Bureau of Fisheries Laboratory, Beaufort, N. C.

It should be emphasized here that these tests were carried out before the specific toxicity information was available and the materials used on impregnation work were selected more or less at random to include a wide range of compounds of known general toxicity, so that no possible material would be overlooked.

The railroad ties were furnished by the Pennsylvania Railroad Company through Col. Wm. G. Atwood, of the National Research Council, whose advice and general assistance regarding the problem are gratefully acknowledged. The assistance of Mr. R. S. Perry, Jr., Bureau of Construction and Repair, United States Navy, and Mr. Charles H. Hatsel, Superintendent of the Bureau of Fisheries Station at Beaufort, were of the greatest value in carrying out these tests.

Funds for carrying on this investigation were appropriated by the Quartermaster Corps, U. S. A., the Bureau of Yards and Docks, U. S. N., and the Department of Commerce.

II. HISTORY

A "Digest of Available Information on Marine Borers and Preliminary Recommendations Regarding Study of Methods of Prevention of Their At-

tack" has been written as Report No. E. A. C. D. 247 (1) and includes a fairly comprehensive bibliography. A very extensive bibliography on marine wood boring animals has been compiled by Dr. Barrows, of the National Research Council (13).

The results of the toxicity experiments at Beaufort, N. C., during the summer of 1923, are given in Report No. E. A. C. D. 288, which is appended to this report as Appendix I. The effect of chlorine generated from sea water is described in Report No. E. A. C. D. 286, and the service tests on impregnation are described in Appendix III (E. A. C. D. No. 299).

Harington, in the Third Report of the Committee of the Institute of Civil Engineers (2), describes the chemotropic effect of certain compounds on the larval stages of shipworm, and in this same report are a paper by G. Barger (3) on the investigations to protect timber against *Teredo*, and a general report on creosoting and impregnation of timber, by S. M. Dixon (4).

The Third Annual Progress Report of the San Francisco Bay Marine Piling Committee (5) confirms the conclusion drawn in report E. A. C. D. No. 247 that timber properly impregnated with the right kind of creosote will withstand attack for long periods of time.

Dr. Henry A. Gardner conducted tests with various paints at Beaufort, N. C., during 1922, which were published as Circular No. 176 (6) by the Paint Manufacturers' Association of the United States. In these preliminary tests the efficacy of copper and mercury paints were quite marked and Dr. Gardner has additional tests under way using those materials which showed up best. The results of these tests have not yet been published, but it is believed that there are several surface coatings or paints which will protect as long as they remain intact.

III. THEORETICAL

A. Breeding Season

According to Sigerfoos (7) the breeding season for *Bankia gouldi* at Beaufort Harbor starts about April 15 and continues until about the first of November. The test boards of the National Research Council indicate about the same period.

Dr. Coker (8) indicates that the breeding period for *Limnoria* at the same place is from about the middle of April to December 12 and intimates that the temperature is the deciding factor, the probability being that the production and deposition of eggs by *Limnoria* at Beaufort ceases when the minimum temperature falls to about 14° C., and that the rise of temperature in spring stimulates a renewal of the breeding activity when the minimum temperature rises above 14° C. It would be quite interesting to observe the reaction of *Bankia* in wood blocks to artificially controlled temperatures. It is probable that in this feature there would be a wide variation with different species. However, it is fairly well established that the breeding season is comparatively short along the north Atlantic coast and is at its height during the warm summer months, while in tropical waters the season seems to be all year round, and it may be concluded that warm water stimulates the intensity of attack.

In addition to *Bankia gouldi* and *Limnoria lignorum*, the main types of marine borers found at Beaufort are *Teredo sigerfoosi* and *Teredo navalis*, although these are not nearly so numerous as the other two.

B. Toxic Action of Impregnants

Undoubtedly the comparatively high solubility of creosote and the fact that it "sweats" oil for a considerable period, as can be noted by the oily film of water in the immediate vicinity of creosote impregnated pieces, detract somewhat from its efficiency as an impregnant. In time perhaps enough creosote will come out of the wood, due to solution or mechanical leaching, so that there is not enough remaining to give a lethal concentration in the sea water at the surface of the pile. This would permit the veligers to attach, and once they get a start in the wood a much higher concentration seems necessary for lethal effect than at the free swimming stage.

The specific toxicity data included in this report (Appendix I) are based on the solubility of the toxics in sea water. It is apparent that those compounds which show a definite toxic effect on the organisms will prevent borer attack when used as impregnants so long as they are retained in the wood in such quantity that the concentration of the toxic in the sea water in the immediate neighborhood of the impregnated pile will always be sufficient to kill the embryos. This fact is independent of the question of whether or not the shipworm actually digests, or partially digests, the wood particles. But the toxic concentration is probably confined to the immediate surface of the impregnated piece. This is indicated by the fact that unimpregnated pieces exposed at intervals next to unattacked impregnated pieces all showed decided attack which would not have been the case had the toxic dissolved sufficiently in the sea water to create a reasonably large toxic area.

There is good reason to believe that the wood borings are at least partially digested by teredine borers (9), and there does not seem to be any doubt but that *Limnoria* actually digests the wood. This being the case, even though the toxic were leached out of the impregnated piece beyond the point where a lethal concentration would be maintained at the surface of the wood, there might be sufficient remaining in the wood to be lethal when taken internally over a period of time.

There are so many factors influencing the solution of the toxic once it is in the wood, such as the capillary attraction of the wood and the possible formation of compounds with the wood, that it would be impossible to calculate the length of time necessary to completely dissolve it out. It is believed that with a compound which is soluble in sea water only to the extent of approximately 1 part per 100,000, sufficient will remain in the wood to insure against attack during the economic life of the structure. It is stated that piles which have been in water for thirty years have been removed and showed no evidence of radial penetration of the sea water beyond two or three inches. This would indicate the difficulty of leaching out any material which was thoroughly imbedded in the pores.

C. Theory of Impregnation

The general theory of impregnation is based on the fact that the pores of the wood contain air and moisture, which must be removed in order to allow the impregnant to penetrate. The preservative may just coat the wood fibers, or completely fill the pores, or it may form a chemical combination with the constituents of the wood, as the case may be. A portion of the original moisture on the wood may be removed by seasoning or air drying. The air and some residual moisture may be removed by placing the wood

in cylinders, which are under reduced pressure for a reasonable period, and then allowing the impregnating liquid to be drawn into the evacuated cylinders and sucked into the more or less empty pores of the wood. The application of pressure at this stage will force the liquid even deeper into the wood.

In the open tank process, the air and moisture are removed by placing the wood in a medium which has a higher boiling point than water. When the temperature of the medium is raised above the boiling point of water, the heated air from the pores expands and the moisture is partly driven off as steam. As the wood is allowed to cool in the impregnating liquid, the expanded air contracts, forming a partial vacuum in the pores of the wood and thereby permitting the liquid to enter the pores of the wood more freely.

D. Character of Ideal Impregnant

The ideal impregnating material for marine piling should be highly toxic both to *Limnoria lignorum* and shipworms; it should not injure the wood; it should be only very slightly soluble in sea water at ordinary temperatures, but it should be sufficiently soluble to insure a toxic concentration in the immediate vicinity of the surface of the pile, or be sufficiently soluble in the digestive fluids of the borer to produce lethal effect. In addition, it is desirable that it have a preservative action on the wood itself. For purposes of economy, it would be desirable to use water as a medium for introducing the toxic materials into the wood. It would be highly advantageous if the material were sufficiently soluble in hot water, and sufficiently insoluble in sea water at ordinary temperatures (up to 90° Fahr.), to precipitate the desired quantity of toxic in the wood on cooling. This would permit of impregnation by one of the standard processes.

In case a material cannot be found which is soluble in hot water and rather insoluble in sea water at the ordinary temperatures, it should be soluble in some cheap medium which could be used as a vehicle in the impregnating process. This fact has been taken advantage of in certain U. S. Patents (10) in which petroleum and paraffine are suggested as carriers.

An alternative method which might be more desirable than the use of a fairly permanent vehicle for the toxic would be the use of a volatile solvent which could be recovered after impregnation, leaving the toxic in the wood. This would necessitate the use of a vacuum or vacuum and pressure process for impregnation, as these solvents would naturally have a considerably lower boiling point than water and, therefore, render the ordinary boiling process impracticable.

Still another possibility is the use of a material which is itself soluble in water or in whatever solvent it is desired to use but which forms a more or less insoluble compound with the wood itself. It is open to question whether this compound should necessarily be toxic, although it is preferable that it should, as the formation of a compound which would be indigestible or unpalatable to the borer might be sufficient. Most of the organic dyestuffs would fall in this class.

IV. REVIEW OF EXPERIMENTAL WORK

A. Toxicological and Biological

1. Review of Data—The toxicological investigations were carried out at Beaufort, N. C., during the summer of 1923 by M. S. Allen, of the Medi-

cal Research Division, Chemical Warfare Service, assisted by R. H. Carter.

Laboratory toxicity tests of different compounds were conducted on *Limnoria*, shipworm embryos, exposed shipworms (*Bankia* removed from their burrows), and shipworms in wood blocks.

It is of especial note that the order of toxicities of the compounds tested was in general the same for all four series. The decreasing order of resistivity of the organisms was: embryos, exposed shipworm, *Limnoria*, and shipworm in blocks.

The complete details of the toxicity tests are included in Appendix I, but it should be mentioned here that of the 45 compounds tested, the following stood out in the order named from all the rest in all round toxic value:

Chlorvinyl arsenious oxide
Phenyl arsenious oxide
Mercuric oxide
Mercuric chloride
Mercuric arsenate
Cuprous cyanide
Cupric orthonitrobenzoate
Cuprous chloride
Mercuric anilinate
Mercuric benzoate
Crystal violet

Between these compounds and the others, there was a wide gap. The fact that the exposed *Bankia gouldi* were transferred to fresh sea water as soon as they were apparently killed by the toxic, and usually showed no recovery, indicates that the criteria of death were fairly accurate. Practically all the toxics had a marked fixative action on the dead organisms and deterioration was not nearly so marked as in the plain sea water. By changing the water daily, over 50 per cent of the specimens of *Limnoria* were kept alive for a month and, in view of the greater ease in collecting and handling this species, it may be that a very fair rating for a toxic can be obtained by determining its action on *Limnoria* alone.

In addition to the data included in Appendix I, Carter ran a series of toxicity tests on *Limnoria* and exposed *Bankia gouldi*, using the ordinary salts of various metals, the salts used being the chloride, nitrate, acetate, and sulphate, respectively. The results of this investigation showed that it made very little difference what salt of the particular metal was used, but that the metals rated as follows on all round toxic value: mercury, copper and zinc, in the order named.

Of the other metals, aluminum had a pronounced effect on *Limnoria* but was not tried on exposed *Bankia*. Barium was fairly toxic to *Bankia* but practically neutral to *Limnoria*, while manganese, magnesium, lead, tin, and iron had practically no toxic value in the form used.

In this work the solutions were made up of one part of the metal to the required dilution of sea water. All the barium compounds were less soluble than one part of barium to 100,000 parts of sea water, as were the copper and mercurous compounds.

The particularly interesting feature of this work is that it confirms Dr. Gardner's observations on mercury and copper paints (6) and serves also as a check on the general toxic value of mercury and copper salts found by Miss Allen.

Two test boards containing removable blocks, 6 inches x 4 inches, were made up according to the specifications of the National Research Council Committee on Marine Piling Investigation, and these blocks were removed monthly and sent to Mr. Clapp, at Harvard University, for examination and classification. The analyses of these blocks are included in the report of the National Research Council for 1923. There was no attack on the block sent to Mr. Clapp December 8, 1923, which had been exposed thirty days, indicating that the breeding season had ceased some time prior to that date. Originally these blocks were fastened to a base board by means of screws, but the board became so badly dilapidated because of the marine borer attack that it had to be replaced and an iron rack is now being used.

The accompanying small photographs demonstrate that the shipworm will cross a crack. (Fig. 32). The block (left) was removed from the base board (right) after three months' exposure. The face of the block in the picture shows distinctly that the borers passed through the base board into the block. It was observed at the Bureau of Fisheries Laboratory that shipworms frequently crossed gaps of at least 1/16-inch from one piece of wood to another, which fact shows the fallacy of the old belief that the *Teredo* will not cross a crack.

While too much stress should not be put on the average weight of wood excavated per shipworm per day (0.05 grams) in Miss Allen's report, it is interesting to note that this figure is five times that estimated in E. A. C. D. No. 247 (1), and indicates that it should not be hard to establish a lethal concentration within the body of the *Teredo,* provided the toxic does not form with the wood a much more insoluble compound than the toxic itself.

The only available data on the specific toxicity of creosote are given in Dr. Shackell's work (11) (12) on the emulsions of creosote and creosote fractions on *Limnoria* and exposed *Bankia.* Unfortunately, the concentrations he used were usually about 4 parts of the toxic to 10,000 parts sea water, which is about forty times the concentration used by Miss Allen. In addition, he considered the toxic time as the time required to kill fifty per cent of the organisms, while Miss Allen took 90 to 100 per cent deaths as her criterion. No definite estimate of the comparative toxicity of creosote and the specific toxics placed by Miss Allen at the head of her list can be drawn, but it is believed that her most efficient all around toxics are at least forty times as effective as creosote, from a lethal standpoint.

2. **Future Work**—It is hoped to fill in the gaps in the toxicity table in Miss Allen's report during the summer of 1924, and also to make careful determinations of the toxicity of various creosotes which will be comparable to the other toxicity data. In addition, it is planned to determine the efficacy of a number of additional compounds, and a sufficient number of wood blocks of the size found most advantageous for laboratory work will be planted in time to insure sufficient specimens for these investigations.

B. Prevention of Attack on Existing Structures

1. **Review of Data**—In accordance with the procedure outlined by the inventors, a test was carried out at Beaufort, N. C., July 1, 1923, of a method of generating chlorine by the electrolysis of sea water, and it is sufficient to state here that there was no evidence of the extremely beneficial effects claimed by the sponsors of this process.

Evidence of the toxic effect of metallic copper and compounds formed by the action of sea water on metallic copper seemed definite enough to warrant

the trial of copper studded test pieces. Col. Atwood, of the National Research Council, found that when some of the test blocks which were already attacked by teredine borers were wrapped with copper wire, not only was there no further attack, but the borers already in the block were killed. In Table I in Appendix III of this report, there is a record of two pieces, Nos. 16-1 and 16-2, respectively, which were studded with copper tacks on $\frac{1}{4}$-inch and $\frac{3}{8}$-inch centers, respectively, over the entire surface of the wood. In 16-1 the "tacks" were simply short pieces of No. 16 gauge copper wire about $\frac{3}{8}$-inch long, and in 16-2, ordinary copper carpet tacks were used. Both pieces were practically immune from attack, although 16-1 did have one small *Teredo* hole near a knot, where it was impossible to put any copper wire pieces.

It was hoped that, if the exigencies of the situation demanded, the surface of the piles already in the water could be covered with copper slugs or shot by some such means as an air pressure gun. This work would, of course, necessitate the use of a diver, and the expense would undoubtedly be too great, except in the most desperate case, as the single cost of the necessary cleaning of the barnacles, slime, and other marine growths from the pile would be prohibitive.

FIG. 32—SHOWING THAT SHIPWORMS WILL CROSS A CRACK

2. **Future Work**—The possibility of the use of slowly soluble specific toxics in the sea water in the immediate vicinity of infested piling is, of course, apparent in considering the protection of structures already in place. So little is known of the dispersion of small quantities of difficultly soluble materials in extremely large bodies of water that it did not seem feasible to try any large scale poisoning of the water in Beaufort harbor on account of the fishing industry there, and at this writing no place seems available for a test of this kind.

There is no doubt that there are a number of materials which would kill both larval and full grown shipworms and *Limnoria* if placed in the water in the immediate vicinity of infested structures, but they would also undoubtedly kill nearly all forms of marine life over the same area and an additional region, depending on the local harbor conditions, such as tide, current, winds, etc. All the eleven toxics enumerated under IV-A-1 would

be efficacious for this use, and it is likely that a number of cheaper arsenicals, such as calcium arsenate, as well as other compounds, could be used to advantage. There should be sufficient of the toxic placed in the water to create a toxic area immediately around each pile having a concentration of at least one part of toxic to 100,000 parts of sea water for a period of from five to seven days. The material could be suspended in cloth or porous tubes cf small diameter (one inch or less) along the entire length of each pile, and kept in place by fastening to the pile at the top, and by having a weight at the bottom end of the tube. It is probable that this treatment could be installed for about $2 per pile for the cheaper toxics. It would have to be repeated at fortnightly intervals, or certainly no longer than monthly intervals, during the breeding season. These data are based mainly on conjecture, and actual tests are necessary before they can be accepted with any great assurance, and even then the local conditions mentioned before would cause wide variations. A better surface distribution might be secured by the use of a cloth tube wound around the pile in the form of a helix, having the toxic in its core, although it is doubtful whether this would be necessary. It might be that by the use of a non-toxic material of the same degree of solubility as the toxic which it is desired to use, both the speed of solution of the material and the distribution of the concentration of the material over the surrounding water could be fairly accurately determined. Possibly this might be carried out using some innocuous dye, and the concentrations in the surrounding water determined by colorimetric methods. There is a possibility that in a land locked harbor, with a number of timber structures to protect, the amount of toxic necessary to insure protection for each might eventually be such that the whole harbor would be polluted and it will be necessary to ascertain the limits of dispersion for non-toxic compounds of the same degree of solubility as the toxics which it is desired to use before any actual poisoning test can be made.

C. Protection of New Structures

1. Discussion—The data from the service tests at Beaufort, as described in Appendix III, indicate that certain toxics, when used as impregnants, give definite protection against marine borers for a short period of time. How lasting this protection will be, it is impossible to state on the basis of tests made to date, but when the service test data are studied in conjunction with the specific toxicity data, there is certainly basis for the presumption that several of the materials used in the service tests will probably protect for 30 years or more. In fact, the results of the investigation of the San Francisco Bay Marine Piling Committee, as published in their Third Annual Progress Report (5), show that protection for a period of from 15 to 20 years can be secured by proper creosote impregnation, and this narrows the problem of protection of new structures to the point of finding a material which will give protection for a longer period than creosote, or of finding a cheaper material than creosote, which will give equal protection, or of finding a material cheaper than creosote which will give protection for a longer time.

There is no doubt that the addition of a specific toxic to creosote will give protection for a longer period than creosote alone.

It is quite probable that with the use of some cheaper vehicle than creosote, several of the specific toxics found, when used in this vehicle, will give protection equal to creosote for less cost.

It is possible that when all the data are available, one or more materials will be found which will give protection for a longer period than will creosote, and at less cost.

In the service tests, creosote was used as a vehicle for a great many of the toxics as it was hoped that by the use of sheathed pieces the relative efficiency of the specific toxics would be indicated. It was shown by Shackell (12) that a shipworm will pass from an untreated piece of wood into a creosoted block and, if after going through the sheathing into a block impregnated with creosote plus a specific toxic, the borer was killed, stopped, or repelled, there could be no question but that the toxic, and not the creosote, did the work. As explained in Appendix III, it was some time before the right kind of sheathing was developed, and by that time, it was too late for shipworm attack. It is hoped that the data will be available by the end of next summer.

Most of the service tests using carriers other than creosote were exposed too late to obtain any definite results; consequently, these pieces, along with others, making fifty in all, are still being exposed at Beaufort. Although there will be no new attack until next spring, the toxics will have an opportunity to partially leach out, and the borers already in the sheathing will have a chance to penetrate to the treated block. After the breeding season commences, these pieces will be inspected from time to time for indication of attack, and will finally be withdrawn about the close of the breeding season in the fall.

2. **Future Work**—The large scale apparatus shown in the accompanying photograph (Fig. 33) is designed for the impregnation of round fence posts by the temperature-vacuum-pressure process. These posts are 8 feet long with an approximate diameter of 4 to 6 inches. It is planned to impregnate sets of ten posts each with the same toxic, and expose them at Beaufort before the breeding season commences, to serve as long time tests for the most promising materials. It is planned to pull one post per year at the close of the season, and make a thorough examination for evidence of attack. Among the materials which will be used for this work are diphenylchlorarsine, diphenylaminechlorarsine, crystal violet, phenylarsenious oxide, and others.

A set of creosote impregnated posts will be run as a check. Each set of posts will be impregnated by the process best adapted for the particular toxic used.

The use of different vehicles to carry the toxics will be investigated and it is planned to try other solvents than creosote in order to cut down the cost. Preliminary work will be carried out with the smaller test pieces, although fuel oil will probably be tried out as a vehicle for some of the more toxic arsenicals on a larger scale.

It is probable that smaller percentages than 5 per cent of the more toxic materials will prove effective and it is planned to try as low as 1 per cent of these compounds.

V. CONCLUSIONS

1. All of the impregnated pieces used gave much better protection against marine borer attack than unimpregnated pieces.

2. The most efficient all around toxics with regard to the four types of

marine borers studied, are as follows, in the order named:

Chlorvinyl arsenious oxide
Phenyl arsenious oxide
Mercuric oxide
Mercuric chloride
Mercuric arsenate
Cuprous cyanide
Cupric orthonitrobenzoate
Cuprous chloride
Mercuric anilinate
Mercuric benzoate
Crystal violet

Between the efficacy of these compounds and that of the other materials tested, there is a wide gap.

3. The addition of 5 per cent of specific toxics, such as diphenylchlorarsenious oxide, diphenylaminechlorarsenious oxide, phenylarsenious oxide, etc., to creosote for impregnation purposes would seem to afford definite protection for piling against marine borers.

4. While the length of exposure was not sufficient to justify too optimistic conclusions, it is believed that piling so impregnated will stand up for a longer period than straight creosote impregnated piling.

5. While quite a few compounds of undoubted toxicity have been found, the choice of the best all around toxic for impregnation work will eventually depend upon the comparative economy of material and process cost in introducing the same.

6. The cost of the carrier for the toxic will probably prove the determining factor in the choice of the best all around toxic. Economically, the carriers used are as follows, in order of cheapness:

a. Water
b. Fuel oil
c. Benzol (figuring recovery)
d. Ammonia
e. Creosote

7. If a method can be perfected using toxic dyes in water solution which will obtain the desired depth of impregnation, and which are fast to sea water, they will probably prove the most economical of the compounds used.

8. It is believed that most of the impregnation results can be duplicated on large scale apparatus sufficiently well for practical purposes.

9. The toxicity results indicate that *Limnoria* can be used as a criteria for the specific toxicity of any compound on all the types of marine borers studied.

10. There is no doubt that shipworms will cross a crack between one piece of wood and another, provided the gap is not too great.

11. The specific toxicity effect of various creosotes on marine borers should be determined.

12. A test should be carried out using a material which is very slightly soluble in sea water, and which is non-toxic to marine life in order to determine the time required to dissolve the same when suspended in cloth tubes of about 1 inch diameter along the side of piling.

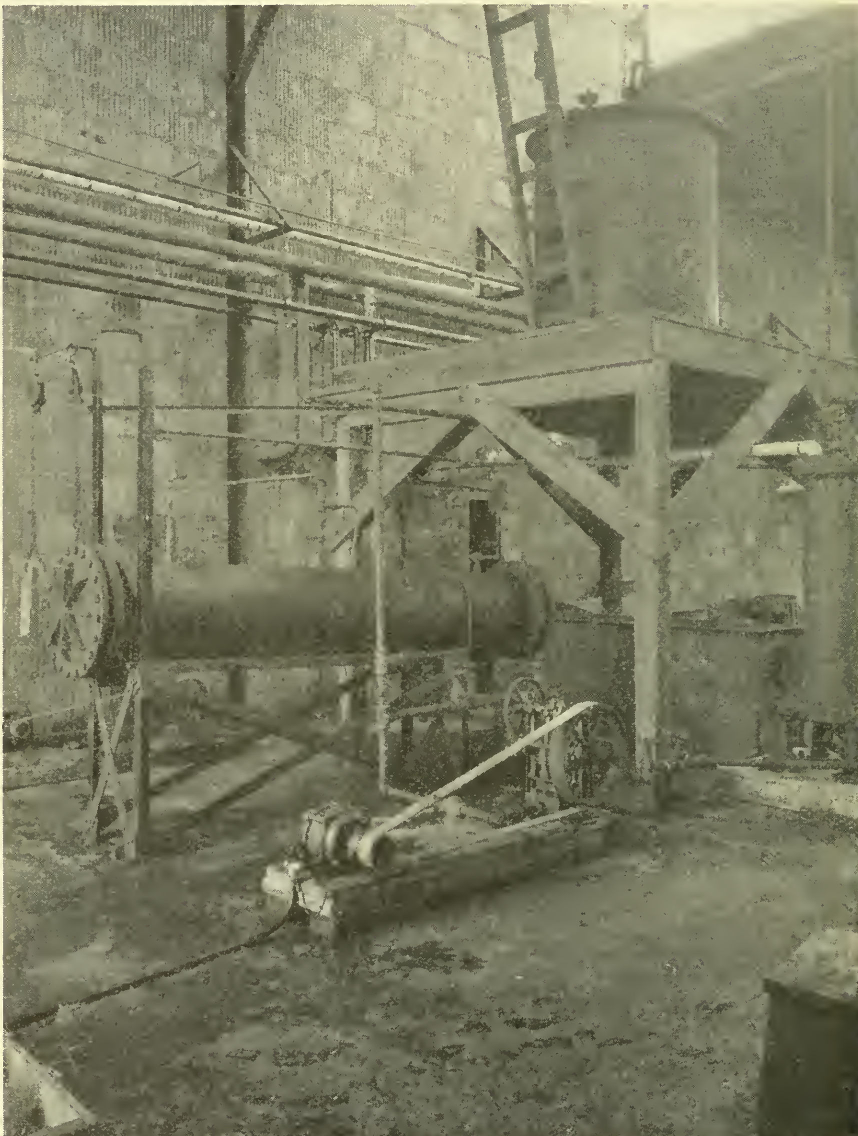


FIG. 33—"LARGE SCALE" VACUUM-PRESSURE IMPREGNATING APPARATUS

13. Additional work is necessary before final conclusions can be drawn and the expense of pile protection estimated.

VI. BIBLIOGRAPHY

1. **Walker & McQuaid**—Digest of Available Information on Marine Borers and Preliminary Recommendations Regarding Study of Methods of Prevention of Their Attack.

   Chemical Warfare Service Report No. E. A. C. D. 247.

2. **Harington**—Third (Interim) Report of the Committee of the Institution of Civil Engineers for 1923, page 27.

3. **Barger**—Third (Interim) Report of the Committee of the Institution of Civil Engineers for 1923, page 24.

4. **Dixon**—Third (Interim) Report of the Committee of the Institution of Civil Engineers for 1923, page 37.

5. **Third** Annual Progress Report of the San Francisco Marine Piling Committee, February 20, 1923, page 13.

6. **Gardner**—Circular 176 of the Paint Manufacturers' Association of the United States, Scientific Section, "Marine Borer Paints," May, 1923.

7. **Sigerfoos**—Natural History, Organization, and Late Development of Teredinidae, or Ship Worms, Bureau of Fisheries Document No. 639, 1907

8. **Coker**—Breeding Habits of Limnoria at Beaufort, N. C., Journal Elisha Mitchell Scientific Society, Vol. XXXIV, Nos. 1 and 2, August, 1923.

9. **Dore and Miller**—The Digestion of Wood by Teredo Navalis, University of California Publications on Zoology, Vol. XXII, No. 7, pages 383-40, February 1, 1923.

10. **Bartsch**—Method of Wood Protection—

    U. S. Patent No. 1,374,806.

    Ellis—Process of Preserving Wood—U. S. Patent No. 1,017,636.

11. **Shackell**—Comparative Toxicity of Coal Tar Creosote and Creosote Distillates, and of Individual Constituents for the Marine Wood Borer, Xylotrya, Proc. of American Wood Preservers' Association, 1915, page 233.

12. **Shackell**—Marine Borers from the Wood Preservers' Standpoint, Proc. of American Wood Preservers' Association, 1916, page 127.

13. **Barrows**—Bibliography on Marine Wood Boring Animals, National Research Council, Washington, D. C., April 16, 1923.

APPENDIX I

Table of Contents

APPENDIX I

TOXICITY OF CERTAIN COMPOUNDS ON MARINE WOOD BORING ORGANISMS TOGETHER WITH SOME PHYSIOLOGICAL CONSIDERATIONS

October, 1923

By M. S. Allen and R. H. Carter

ABSTRACT

The object of the investigation was to test certain compounds for their toxicity on marine wood-boring organisms and to investigate certain physiological facts concerning the Teredine borers.

Substances were tested on *Limnoria lignorum, Bankia gouldi* in an exposed state, on the swimming embryos of *Bankia gouldi* and on *Bankia gouldi* in wood blocks. The toxicity of the various compounds was approximately the same for the various organisms. The embryos of *Bankia gouldi* were obtained by artificial fertilization of the ova, and were successfully raised to the veliger stage.

Chlorvinyl arsenious oxide, phenyl arsenious oxide, mercuric oxide, mercuric chloride, mercuric arsenate, cuprous cyanide, cupric ortho nitro benzoate, mercuric benzoate, and crystal violet were the most toxic out of 45 compounds tested.

The digestive tract of *Bankia gouldi* was found to be neutral in reaction. *Bankia gouldi* was not able to withstand a reduction in salinity lower than 4 parts per thousand.

I. INTRODUCTION

The object of this investigation was to determine the toxicity of certain compounds on marine wood boring organisms, and to investigate certain physiological facts concerning the teredine borers. It was intended to use methods for toxicity tests which were much more rapid than the exposure of treated wood in infested waters. In this manner, obviously useless compounds would be eliminated, and the number to be tested by long time exposures materially reduced.

This work was carried on from June 18 to September 15, 1923, at the Marine Biological Station of the United States Bureau of Fisheries located at Beaufort, N. C.

The invaluable direction and assistance rendered by Dr. A. W. Bray is gratefully acknowledged, as is also the cooperation of Mr. Chas. H. Hatsel, Superintendent of the Station, and Mr. R. H. Perry, Jr.

The biological station is located on a small island about 100 yards from the mainland. The channel from Bogue Sound and the ocean bound the south and east sides; to the north and west there is open, shallower water.

Wooden structures on all sides of the island are heavily attacked by teredine borers and by the crustacean, *Limnoria lignorum*.

II. MATERIALS

A. Organisms

Limnoria lignorum and *Bankia gouldi* were the species used in all the toxicity tests. *Limnoria lignorum* is a small crustacean about 3 mm. long which is found in enormous numbers in wooden structures between the high and low tide marks. It makes tunnels about one millimeter in diameter running near the surface of the wood. Specimens were obtained easily from wood chipped off piles near the dock.

Bankia gouldi is the shipworm found in the greatest numbers in the vicinity of the island. The eggs of *Bankia* are fertilized after extrusion from the female and go through their embryonic life independently of the adult—not being carried in the gills as are those of some species of *Teredo*. At the time of attachment to wood the young *Bankia* has the form of a small bivalve. The bivalve shells are used to excavate a burrow which the animal digs to accommodate its rapid growth. The body elongates so that in its adult form it has the modified shells at the anterior end for burrowing and a long tubular body terminating in two siphons, one exhalant, one inhalant, which remain at the point of entrance to the burrow. (1) When disturbed the delicate siphons are withdrawn into the opening which is blocked by an outthrust of the pallets. The burrow is lined with a calcareous material. *Bankia gouldi* differs from *Teredo sigerfoosi*, also to be found there, in its smaller size, in the shape of the boring shell, and in having cone-shaped instead of paddle shaped pallets. For further information on organisms the reader is referred to Report No. E. A. C. D. 247.

Pieces of wood of various sizes were planted in the water on the west and south sides of the island to provide specimens. A large number of hard pine blocks, 2 inches by 4 inches by 8 inches, were nailed onto strips of board and sunk in the water. Several pieces of soft pine, 1 inch by 6 inches, of the type used to sheathe treated pieces and two bales of cedar shingles were planted. The shingles were to obtain small uniform specimens that could be easily chipped out. While they were attacked to quite an extent by *Bankia* the specimens obtained were curiously transparent and delicate, very unlike the firm white specimens found in the pine blocks. The nacreous lining of the burrows in the shingles was thin and fragile and often not continuous. On this account these specimens were not used for toxicity work. A better material for this purpose would have been thin soft pine boards of the type of which boxes are made.

A small number of large specimens of *Teredo sigerfoosi* were obtained from planks which had been in use for some time in the terrapin beds on the north side of the island. These planks contained an occasional specimen of *Bankia*. One specimen of *Teredo sigerfoosi* was found in wood on the other side of the island. Specimens were secured by whittling them from their burrows with a jack-knife.

B. Toxics

All toxicity tests were run with sea water solutions of the substances. Accurate solubility data on these compounds in sea water were not available but for the most part the compounds were only slightly soluble. It was decided to use definite dilutions of 1-50,000 and 1-100,000. If a substance

would not give a clear solution at a concentration of 1-50,000, this dilution was not used. Some few of the compounds (mercury stearate, copper stearate, copper rosinate, mercury rosinate, hexachlorethane, toxall, and diphenylaminechlorarsine) appeared to be insoluble. The barium and copper salts apparently had reacted with the salts contained in the sea water, making the effective solution somewhat less in concentration. In these cases, the compound was shaken with sea water, allowed to stand, and used as saturated solutions. In all other cases, there was no visible turbidity.

The toxicity of mercuric chloride was determined in the same manner as that of the compounds being investigated in order to establish a standard of comparison.

III. EXPERIMENTAL

A. Toxicity Tests on *Limnoria*

Limnoria has the advantage of being small in size, easily obtained and of allowing a large number of tests to be run conveniently and in a comparatively short time.

Twenty specimens of *Limnoria* were used for each test, five in each of four small dishes, in about 30 cc. of the toxic solution in 1-50,000 and 1-100,000 dilutions. When motion appeared to cease individuals were placed under the microscope and observed for signs of life when stimulated by a teasing needle. True death was distinguished from narcosis by removing non-reacting individuals to fresh sea water, and observing them for signs of recovery.

The solutions tested fell naturally into one of two classes: Group A, causing 90-100 per cent death in less than seventy hours; Group B, not causing 100 per cent death in 120 hours. The lethal time in hours was taken for Group A; the percentage dead after 120 hours for Group B.

Twenty controls in sea water were run parallel to each set of tests, a set comprising an average of five toxic substances. Of about 400 individuals so tested as controls, 95-100 per cent were alive at the end of five days.

B. Toxicity Tests on Exposed *Bankia*

By exposing suitable wood, there is no difficulty in obtaining a supply of *Bankia* although considerable time and patience is required to remove specimens intact from their burrows. Specimens showed a high degree of variation in their condition following removal from the wood. The temperature, the amount of handling necessary to secure them, the type of wood from which they were obtained, and other probable factors affected their resistance. Undamaged specimens of *Bankia* survived twenty-four hours in sea water. The period of survival could be lengthened considerably, to forty-eight and even seventy-two hours, by frequently renewing the sea water.

Because of this individual variation, an effort was made in obtaining *Bankia* to secure individuals as uniform in size and appearance as possible, those between 2-4 cm. in length being preferred. They were used as soon as possible after being whittled from their burrows. Only specimens reacting vigorously when their siphons were touched with a teasing needle and being perfectly intact as to mantle were used. Three individuals in 150 cc. of the solution in a finger bowl were used for each test in dilutions of the toxics of 1-50,000 and 1-100,000. Three specimens in sea water were run

TABLE I—*Limnoria*

A. HOURS TO CAUSE 90–100 PER CENT DEATHS

	AT DILUTION OF 1–100,000	AT DILUTION OF 1–50,000
Phenylarsenious oxide	4½	3
Chlorvinylarsenious oxide	..	4
Mercuric chloride	8	4
Mercuric oxide	..	7½
Mercuric anilinate	..	24
Cuprous cyanide	66	25
Cuprous chloride	69	45
Mercuric benzoate	..	48
Cupric orthonitrobenzoate	69	53
Mercuric arsenate	69	69
Benzanilide	69	69

B. PER CENT DEATHS AT 114–120 HOURS

	DILUTION OF 1–100,000	DILUTION OF 1–50,000
Paranitrobenzoic acid	100	90
Paris green	95	..
*Mercuric rosinate	85	..
Cupric paranitrobenzoate	80	95
*Cupric rosinate	80	..
*Hexachlorethane	80	..
Aloes	70	85
Poke root	70	85
Triphenylarsine	70	70
Diphenylamine arsenious oxide	70	..
*Toxall	60	..
Diphenyl arsenious oxide	50	..
Lead orthonitrobenzoate	45	80
Cupric arsenate	40	..
*Cupric stearate	35	..
*Mercuric stearate	35	..
Benzil	30	..
Calcium fluoride	20	35
Cupric arsenite	20	..
Orthonitrobenzoic acid	15	35
Antimony pentoxide	10	..
Crystal violet	..	55
Cupric tannate	..	45
Direct black	..	40
Cupric benzoate	..	40
Methylene blue	..	30
Direct blue	..	20
Control (in sea water) 5%		

*Not soluble at 1–100,000 parts sea water and run as saturated solutions.

Note—1. Toxall is a preparation made by Toch Bros., New York City, and is stated to be barium phenocresylate in creosote.

2. All barium and copper salts formed slight precipitates by reaction with sea water, giving a lower concentration than noted.

as controls with each set of four or five tests. These controls survived 24 hours or longer.

The reaction of each individual was tested at hourly intervals. When no response to the stimulus of the teasing needle occurred, the individual was removed to fresh sea water. In only one case, diphenylamine chlorarsine, did revival follow the transfer, and in most cases death appeared to be practically simultaneous with the absence of response to stimuli. The test recommended by some investigators of observing the appearance of degeneration of the siphons did not seem advisable as some of the solutions used acted as fixatives and preserved the specimen in good condition.

It is difficult to account for the effect which a few solutions appeared to have in prolonging the life of specimens. In saturated solutions of mercuric stearate and mercuric rosinate, to cite the most striking cases, *Bankia* lived for seven days. It is possible the amount of toxic present was just sufficient to prevent the multiplication of bacteria and protozoa in sea water.

C. Toxicity Tests on *Bankia* in Wood Blocks

Testing the exposed *Bankia* had in its favor the short time of survival and the easy method of testing for death. It was thought, however, that the unnatural conditions surrounding the delicate organism upon its removal from the burrow might be so large a factor in producing death as to distort the toxicity data.

With the idea of eliminating extraneous harmful influences *Bankia* were tested in toxic solutions without being removed from the wood. To some extent the method followed was that used by Blum in his work on the effect of low salinity on *Teredo.* (2) Fortunately, there were some long, smooth-surfaced, 4 x 4-inch timbers remaining from other experiments which were well attacked without being riddled by *Bankia.* These were sawed into 8-inch lengths, and placed for a few days in glass aquaria of 6 liter capacity in gently running sea water. When the timbers were removed from the harbor the pallets were extruded and the siphons withdrawn. A gradually increasing number of siphons appeared after the block was placed in the aquarium. The number of siphons extruded was counted several times a day until a maximum and fairly constant count was obtained. The block was then placed in a toxic solution of 1-50,000 dilution and allowed to remain for seven days.

This strength of solution and length of exposure was adopted as a standard test after several trials with various combinations of the dilution and time elements. A 1-100,000 dilution was too weak to give pronounced results with any but a few of the most toxic solutions. Since most of the toxic substances were soluble at 1-50,000 and not much higher, this dilution was chosen. Short exposures, 6 to 24 hours, had no effect whatever, even with the most toxic solutions. Three-day exposures were satisfactory with the more toxic solutions; useless with the less toxic ones. The solutions were renewed every other day; oftener if necessary to prevent growth of ciliatos and mold.

A carefully counted block was run as a control in sea water parallel to each week's exposure. The control block was kept in standing sea water which was changed as often as the toxic solutions were changed. The end of seven days frequently showed a decrease in the number of siphons extruded, but the return to running sea water brought out the original number and, in most cases, a larger number of siphons.

When a block was removed from water to a toxic solution the mere withdrawal of the block from water caused retraction of the siphons. In some cases, they were extruded soon after immersion in the toxic. In the case of mercuric arsenate no siphons appeared either after the block was placed in the solution, or when after seven days it was restored to water. This case was unique. With phenyl arsenious oxide, the effect, although decided, was

TABLE II. EXPOSED BANKIA

COMPOUND	NUMBER OF HOURS TO CAUSE DEATH	
	DILUTION OF 1–100,000	DILUTION OF 1–50,000
Chlorvinyl arsenious oxide	..	2
Phenyl arsenious oxide	2	3
Mercuric oxide	..	3½
Cuprous cyanide	..	3½
Mercuric chloride	..	4
Mercuric arsenate	..	5½
Cuprous chloride	..	6
Cupric orthonitrobenzoate	..	11
Paris green	9	..
Crystal violet	..	7
Cupric arsenite	7	..
Cupric arsenate	7	..
Barium arsenate	7½	..
Cupric benzoate	..	8
Methylene blue	..	8
Cupric paranitrobenzoate	..	11
Mercuric anilinate	..	11
Barium nitrate	16	..
Barium acetate	16	..
Ferric orthonitrobenzoate	16	..
Diphenylamine arsenious oxide	21	..
Diphenyl arsenious oxide	48	..
Cupric tannate	..	48
Quinine sulphate	..	72 (2 dead at 12; 1 alive at 72)
Benzanilide	..	74 (2 dead at 22; 1 alive at 74)
Direct blue	..	7 (1 dead)
*Cupric rosinate	48 (1 alive)	..
Mercuric benzoate	..	48 (2 alive)
Direct black	..	48 (all alive)
Diphenylamine chlorarsine	..	6†
*Cupric stearate	42 (all alive)	..
Paranitrobenzoic acid	..	96 (2 alive)
*Mercuric stearate	7 days	..
*Mercuric rosinate	7 days	..

Control (3 in sea water)—All alive at 24 hrs.

*Not soluble in 1–100,000 parts sea water and run as saturated solutions.

†No reaction to teasing needle, but all revived in sea water.

Note.—Barium and copper salts formed slight precipitates by reaction with sea water, giving lower concentrations than noted.

delayed. When the block was changed back to water, twenty-five siphons appeared, the second day there were four, and from then on only three. In most cases, a small proportion was extended during exposure with a return of a larger percentage after removal to sea water.

Withdrawing the block from water brought out a large number of pallets, jarring the block brought out still more, but placing the blocks in toxic solutions, while causing the withdrawal of a large number of siphons, did not cause the extrusion of a similar number of pallets. In some cases the unblocked holes could be recognized. At no time, in any toxic solution was the number of pallets extruded equal to the number of siphons previously counted.

The length to which the siphons were extended depended, of course, upon the size of the individual and to a lesser extent upon its state of activity. Three to four cm. was the greatest extension observed. The average was 1 to 1½ cm. Generally the siphons, when extruded in the toxic solution, were extended a shorter distance than in sea water. The greatest extension, 2 and 3 cm., was shown in a solution of Paris green. Upon changing the blocks back to sea water after exposure, it was noticed that the siphons were extended to a greater distance than usual. A lack of suitable blocks prevented tests being made on all the solutions on hand.

While the use of *Bankia* unremoved from the wood has a decided advantage in approximating more nearly natural conditions, there is greater difficulty in securing suitable material and the time and space required are considerable. Occasionally, the maximum number of siphons does not appear for several days. The cases where the number of siphons counted after exposure was greater than before is due to this tardiness in extending the siphons; although in all of these cases the siphons were counted for a week or more before the block was placed in the toxic solution. The combination of the block exposure and the exposed *Bankia* makes a dependable test of a toxic.

D. Toxicity Tests on *Bankia* Embryos

Attempts to fertilize the eggs of *Teredo* artificially were made repeatedly during the course of the summer. The first successful results were obtained with large specimens of *Teredo sigerfoosi* found in planks from the terrapin beds on the north side of the island. Mature eggs were secured from one large female, and fertilized with sperm from one of the few males found at that time. Segmentation of the eggs took place rapidly and normally. In four hours the trochophore stage was reached and the embryos began to swim. They were kept alive three days and had reached the free swimming veliger stage with a distinct shell formation before the volume of water necessary to keep them alive rendered them impossible to find. No inclination to settle on wood was shown during this time.

One female *Teredo sigerfoosi* was found later in the season in wood otherwise containing only *Bankia gouldi;* it contained mature eggs, which were fertilized artificially with sperm from a male *Bankia.* The eggs developed normally, and reached the free swimming stage. They did not differ, as far as could be seen, from embryos of unmixed parentage, but died after forty-eight hours.

The *Bankia* were very difficult to raise. The eggs were fertilized easily and segmentation commenced in a large number of trials but was irregular

and abnormal. This was due undoubtedly to the immaturity of the eggs which were not extruded naturally but had to be teased out of the individual. Three attempts with *Bankia* were finally successful and the toxic solutions were tested on the swimming embryos. It was impossible to use the same number of embryos for each solution but by drawing up the same amount of liquid from the surface of the water in a capillary pipette for each test, a fairly constant number (averaging around fifty) was obtained. The tests were made in Syracuse watch glasses under the dissecting microscope. For fear that the embryo would not reach the advanced veliger stage, the tests were made as soon as swimming became general and vigorous.

In all cases, the time elapsing between the first and last death in each group was short.

TABLE III.—BANKIA IN WOOD BLOCKS

	Dilution	Exposure	Siphons Extended In Sea Water	Siphons Extended After Removal from Toxic	Percentage Death
Mercuric chloride	1-100,000	3 days	95	44	54
Phenyl arsenious oxide....	1-100,000	3 days	113	66	42
Cuprous cyanide	1- 50,000	3 days	91	59	36
Mercuric arsenate.......	1- 50,000	3 days	29	19	35
Mercuric oxide..........	1- 50,000	3 days	126	87	31
Cupric orthonitrobenzoate.	1-100,000	3 days	75	57	24
Zinc cyanide............	1- 50,000	3 days	117	123	..
Mercuric arsenate........	1- 50,000	7 days	89	0	100
Methylene blue..........	1- 50,000	7 days	23	0	100
Mercuric rosinate........	Sat. Sol.	7 days	33	0	100
Mercuric oxide..........	1- 50,000	7 days	99	1	99
Phenyl arsenious oxide ...	1- 50,000	7 days	70	3	96
Crystal violet............	1- 50,000	7 days	33	4	88
Chlor vinyl arsenious oxide	1- 50,000	7 days	34	6	83
Mercuric anilinate.......	1- 50,000	7 days	42	32	75
Cuprous chloride.........	1- 50,000	7 days	34	47	..
Mercuric benzoate.......	1- 50,000	7 days	39	62	..
Cupric tannate..........	1- 50,000	7 days	50	50	..
Cupric benzoate.........	1- 50,000	7 days	43	55	..
Direct blue..............	1- 50,000	7 days	31	41	..
Direct black.............	1- 50,000	7 days	28	27	..
Paris green.............	1-100,000	7 days	38	42	..
Diphenylamine chlorarsine	Sat. Sol.	7 days	24	25	..
Cupric rosinate..........	Sat. Sol.	7 days	39	39	..
Cupric stearate..........	Sat. Sol.	7 days	38	36	..
Toxall	Sat. Sol.	7 days	29	27	..
Control Block............	Sea Water	3 days	90	95	..
Control Block............	Sea Water	3 days	97	107	..
Control Block............	Sea Water	7 days	100	110	..
Control Block............	Sea Water	7 days	33	38	..
Control Block............	Sea Water	7 days	29	28	..

Once the initial difficulty of raising them is passed, the test on *Bankia* embryos is very satisfactory. They are obtainable in vast numbers, are easily handled, and in the veliger stage swimming is vigorous and the cessation of movement easily observed under the microscope. Individual variation in resistance to a given toxic is very slight. This is not true of adult *Limnoria* where the individual variation is high.

E. Discussion of Toxicity Results

The time involved in preparing a large number of specimens for experiments, and the small amount of toxic materials available in certain cases, made it impossible to conduct a sufficient number of tests to give complete data. However, certain general conclusions can be made from a study of the tables. To facilitate comparisons, a collected table is given, in which the data of the four preceding studies are summarized. Due to the many variables in the experiments, no precise order of toxicities can be given, but definite comparisons of the toxicity of a given solution to the different organisms is clearly shown. This summary of the toxicity tests is shown in Table V.

TABLE IV.—BANKIA EMBRYOS

	Number of minutes to cause 100 per cent deaths			
	Sept. 5 1-50,000	Sept. 5 1-100,000	Sept. 12 1-50,000	Sept. 13 1-50,000
Phenyl arsenious oxide	...	5	1	1½
Chlorvinyl arsenious oxide	1½	3½	...	2½
Mercuric chloride	...	6½	...	3½
Mercuric arsenate	3	...	...	...
Mercuric oxide	5	...	3½	5
Crystal violet	9	...	8	...
Mercuric anilinate	30	...	...	...
Cupric orthonitrobenzoate	31	...	...	30
Mercuric benzoate	...	...	40	43
Cuprous cyanide	46	...	...	...
Cupric benzoate	...	...	50	80
Methylene blue	...	...	165	...
Cupric arsenite	...	240	...	...
Cupric arsenate	...	240	...	...
Benzanilide	270	...	240	...
Paranitrobenzoic acid	270	...	240	...
Paris green	...	270	...	...
Cuprous chloride	300	...	120	...
Quinine sulphate	300	...	240	...
Direct black	300	...	240	...
Direct blue	300	...	240	...
Cupric paranitrobenzoate	390	...	240	...
Cupric tannate	...	...	240	...
Control (in sea water)	Freely swimming after 24 hours.			

TABLE V.—SUMMARY OF TOXICITY TESTS

		Bankia Embryos Table IV	*Bankia* Exposed Table II	*Limoria* Table I	*Bankia* in Blocks Table III
		Time to Cause 90-100 Per Cent Deaths			
		Minutes	Hours	Hours	Per Cent Deaths
Chlorvinyl arsenious oxide	(1- 50,000)	1½	2	4	83 7 days
Phenyl-arsenious oxide	(1- 50,000)	1½	3	3	96 7 days
Mercuric oxide	(1- 50,000)	5	3½	7½	99 7 days
Cuprous cyanide	(1- 50,000)	46	3½	25	36 3 days
Mercuric chloride	(1- 50,000)	3½	4	4	54 3 days
Mercuric arsenate	(1- 50,000)	3	5½	69	100 7 days
Cuprous chloride	(1- 50,000)	300	6	45	† 7 days
Cupric orthonitrobenzoate	(1- 50,000)	31	11	53	24 3 days
Paris green	(1-100,000)	270	9	120	† 7 days
Crystal violet	(1- 50,000)	9	7	*	88 7 days
Cupric arsenite	(1-100,000)	240	7	*	....
Cupric arsenate	(1-100,000)	240	7	*	....
Barium arsenate	(1- 50,000)	...	7½	...	....
Mercuric benzoate	(1- 50,000)	40	†	48	† 7 days
Cupric benzoate	(1- 50,000)	50	8	*	† 7 days
Methylene blue	(1- 50,000)	165	8	†	100 7 days
Cupric paranitrobenzoate	(1- 50,000)	390	11	120	....
Mercuric anilinate	(1- 50,000)	30	11	24	75 7 days
Ferric orthonitrobenzoate	(1-100,000)	...	16	...	....
Diphenylamine arsenious oxide	(1-100,000)	...	21	*	....
Diphenyl arsenious oxide	(1-100,000)	...	48	*	....
Quinine sulphate	(1- 50,000)	300	72	...	....
Benzanilide	(1- 50,000)	270	74	69	....
Paranitrobenzoic acid	(1- 50,000)	270	†	120	....
Mercury rosinate	(Sat. Sol.)	...	168	*	100 7 days
Cupric tannate	(1- 50,000)	240	48	*	† 7 days
Diphenylamine chlorarsine	(Sat. Sol.)	...	6	...	† 7 days
Direct blue	(1- 50,000)	300	†	†	† 7 days
Cupric rosinate	(Sat. Sol.)	...	†	*	† 7 days
Direct black	(1- 50,000)	300	†	*	† 7 days
Cupric stearate	(Sat. Sol.)	...	†	*	† 7 days
Mercuric stearate	(Sat. Sol.)	...	168	*	....
Toxall	(1-100,000)	...	...	*	....
Hexachlorethane	(1-100,000)	...	...	*	....
Triphenyl arsine	(1-100,000)	...	...	*	....
Benzol	(1-100,000)	...	...	†	....
Calcium fluoride	(1-100,000)	...	...	*	....
Orthonitrobenzoic acid	(1-100,000)	...	...	*	....
Antimony pentoxide	(1-100,000)	...	...	†	....
Poke root	(1- 50,000)	...	...	*	....
Aloes	(1- 50,000)	...	...	*	....
Lead orthonitrobenzoate	(1- 50,000)	...	...	*	....
Zinc cyanide	(1- 50,000)	...	...	...	† 7 days

*Survived over 120 hr. †No effect.

From the foregoing tables it may be seen that the compounds used are quite consistent in their effects upon *Limnoria*, exposed *Bankia*, *Bankia* embryos, and *Bankia* in wood blocks. The use of the four tests is desirable, when possible, but results from any one of the four alone, when carefully run and controlled, can be depended upon to give a good idea of the value of a compound. The toxicity value of a single compound could be determined by testing it and mercuric chloride simultaneously.

From the foregoing tables, the following compounds have a greater toxicity value than any others, and are arranged in order of toxicity:

Chlorvinyl arsenious oxide
Phenyl arsenious oxide
Mercuric oxide
Mercuric chloride
Mercuric arsenate
Cuprous cyanide
Cupric orthonitrobenzoate
Cuprous chloride
Mercuric anilinate
Mercuric benzoate
Crystal violet

Between these solutions and all the others there is a decided decrease in effectiveness. The value of mercury and copper compounds and of mercury over copper is indicated. Of the dyes tested, crystal violet showed up very well, especially on embryos. Methylene blue was ineffective in all other tests, but gave good results on *Bankia* in blocks. This result is not dependable as the blue dye precipitated out on the wood, the solution becoming colorless. As often as this occurred, the solution was renewed, so that undoubtedly the *Bankia* were exposed to a higher concentration than 1-50,000. This occurred to a lesser degree with crystal violet, direct blue, and direct black, and possibly with other compounds, not dyes, and so not visibly precipitating. This question of precipitation on the wood must be taken into consideration in all compounds so tested, and is a disadvantage in the use of blocks.

It is probable that the substances which were not soluble at a dilution of 1-100,000 are more valuable than the tables would indicate, as even with the minute quantity which must have been in solution when the compounds were considered saturated, there was quite a pronounced effect in some cases.

Shackell has investigated the question of the toxicity of creosote and creosote distillates on *Limnoria* (7) and *Bankia* (*Xylotrya*) (6). He used higher concentrations than any in this report, 0.04 per cent being the lowest he mentions. Valuable comparisons could have been made had a series of tests on creosotes and creosote distillates been made this summer to parallel those on the toxic compounds tested.

Teredo sigerfoosi can block its burrow effectively without extending its pallets to the surface of the wood. Judging from the structure of the pallets and burrow of *Bankia gouldi,* it seems that this animal must have the pallets extended beyond the wood in order to block its burrow. From the number of siphons extended in the toxic solution and the absence of pallets plugging other burrows, it must be concluded that a large number of the *Bankia* in a block are directly exposed to the action of the toxic and that this and not diffusion of the toxic through the wood is responsible for the death of the *Bankia.* Why a solution toxic enough to cause the death of an individual is not strong enough to cause it to retract its siphons or to plug up its burrow is not understood. The greater resistance of *Bankia* in the wood over exposed *Bankia* is due, it would seem, not so much to a lesser contact with the toxic solution as to the favorable conditions attending their remaining in their natural environment.

F. Reaction of the Digestive Tract of *Bankia*

In view of the probability of digestion of the wood taking place in the intestinal tract of the *Bankia*, it seemed advisable to investigate the condition of acidity or alkalinity in different parts of the digestive tract. In case a reaction one way or the other was found it might then be possible to impregnate wood with some substance which, ordinarily very stable, would be soluble or toxic when acted upon by the digestive fluids.

The digestive tract of *Bankia* consists of a short esophagus and a tubular stomach into which opens a saccular cæcum and which leads into a long looped intestine. Apparently the plankton on which the *Bankia* normally subsists is directed into the intestine while the wood borings are stored for a while in the cæcum. It has long been a disputed question whether the *Teredo* digests the cellulose from the borings, but from a recent investigation by Dore and Miller (3) there seems to be little doubt that this is the case, to some extent at least. Since the wood borings are stored in the cæcum and whatever digestion occurs probably takes place there, this organ was selected for testing. It is easily obtained free from other tissues and can be ligated and excised with its contents intact.

The following indicators, sensitive to concentrations of the hydrogen ion ranging from 1×10^{-2} to 1×10^{-9}, were used: methyl orange, congo red, litmus, neutral red, phenolphthalein. Various methods were employed, as follows:

1. Caeca from six specimens were ligated, removed, and passed through several washes of distilled water. They were then opened in 25 cc. of distilled water, and this solution was tested with the range of indicators. A blank of distilled water was run at the same time. This experiment was repeated a number of times, using different sizes of caeca in different conditions of repletion and emptiness.

2. The caeca were ligated, excised, washed in distilled water, and opened under the different indicators under the microscope.

3. Living *Bankia* were immersed in dilute indicators for 24 hours, washed in distilled water, and the caeca removed and examined.

4. Blocks of wood containing *Bankia* were immersed for 3 days in sea water made neutral by hydrochloric acid. They were extracted from the wood and tested as in 2.

5. To neutral sea water was added congo red in 1-5,000 and 1-1,000 dilutions. Blocks containing *Bankia* were immersed in this for from 24 hours to 3 days, after which the *Bankia* were removed and examined.

In none of these tests was there any sign of a change in the indicators. Under the microscope the caeca showed no color change with any of the indicators used. It was impossible to differentiate the solutions of cæcum contents from the distilled water blanks. Any reaction, if present, was so slight as to have little chemical importance.

G. Effect of the Decrease in Salinity of Sea Water on Exposed *Bankia*

A series of tests was made to determine the effects of a decrease in the salinity of sea water on *Bankia* which had been excavated from their burrows. Three *Bankia* were used for each test, ranging in size from 1 cm. to 4 cm., and were distributed as nearly uniformly as possible. Solutions of decreasing salinity were made up by diluting ordinary sea water with soft artesian well water as follows:

DILUTION SEA WATER/FRESH WATER	PARTS NACL. PER 1000	RESULTS
Undiluted	28	All alive in 5 hrs. 1 out of 3 dead in 22 hrs.
1:1	14	All alive in 22 hrs.
1:2	9.3	No reaction in 1 hr., changed to ordinary sea water, all recovered 22 hrs.
1:5	4.6	No reaction in 1 hr., changed to ordinary sea water, 5 out of 6 recovered in 2 hrs. 3 out of 6 dead in 22 hrs.
1:6	4.0	No reaction in 1 hr., changed to ordinary sea water, 5 out of 6 recovered in 2 hrs., 5 out of 6 dead in 22 hrs.
1:7	3.5	No reaction in 1 hr., changed to ordinary sea water, all recovered in 2 hrs., 6 out of 6 dead in 22 hrs.
1:9	2.8	No reaction in 1 hr., changed to ordinary sea water, 1 out of 6 recovered in 2 hrs., all dead in 22 hrs.

At a salinity of 14 parts sodium chloride per 1,000 parts water, *Bankia* were not affected. At 9 parts per 1,000 down to 2.8 parts per 1,000 paralysis occurred within an hour. At 9 parts per 1,000, upon removal to ordinary sea water within an hour, there was a total recovery in 22 hours. Below that, recovery might take place upon removal to normal sea water but the time of survival was shortened. At 4.6 parts per 1,000, 50 per cent survived over 22 hours. At 4.0 parts per 1,000, only 16.7 per cent (1 out of 6) survived, and below that salinity none survived over 22 hours.

These tests on the effect of reduced salinities on exposed *Bankia* were conducted on so few specimens that no definite conclusions can be made. They are interesting, however, in that they correspond very closely to the results of Blum (2) on *Teredo navalis,* using a different method, in which he found that any salinity less than 4 parts per 1,000 was fatal.

H. Effect of the Increase in the Hydrogen Ion Concentration on *Teredo* and *Limnoria*

In order to determine the effect of an increase in the hydrogen ion concentration on wood boring organisms the following tests were performed:

The hydrogen ion concentration of ordinary sea water was found by means of indicator solutions to be approximately 10^{-9} (pH^{-9}). Five *Limnoria* were placed in each of 8 dishes containing about 30 cc. of sea water and allowed to stand. The water was changed every 24 hours to prevent the growth of ciliates. Death or paralysis was determined as in previous experiments. A similar run was made using sea water which had been acidified with hydrochloric acid to a hydrogen-ion concentration of pH^{-2}.

	NO. OF SPECIMENS	NO. DEAD IN 72 HRS.	PER CENT DEAD
Normal sea water— Hydrogen ion concentration between 10^{-9} and 10^{-8} (pH^{-9} and pH^{-8}).....	40	4	10
Acid sea water— Hydrogen ion concentration between 10^{-2} and 10^{-3} (pH^{-2} and pH^{-3}).....	40	34	85

A similar series of experiments was carried out on exposed *Bankia*, using three for each test in about 200 cc. of water.

	NO. OF SPECIMENS	RESULTS
Normal sea water—		
Hydrogen ion concentration between 10^{-9} and 10^{-8} (pH^{-9} and pH^{-8})....	3	All alive after 6 hrs.
Acid sea water—		
Hydrogen ion concentration between 10^{-2} and 10^{-3} (pH^{-2} and pH^{-3})....	3	1 hr. sluggish; 3½ hrs. siphons extended but no reaction; 4 hrs. changed to ordinary sea water; no recovery.

This increase in the hydrogen ion concentration of sea water was fatal. However, the water had been acidified to a point where it was approximately a N/100 solution of hydrochloric acid. This being so much more acid than pure water, imposed a severe test on the individuals. Additional experiments should be conducted where the hydrogen ion concentration is varied only from that of sea water to that of fresh water.

I. Study of the Wood Boring Activities of *Bankia*

In connection with toxicity test on *Bankia* in wood (Section C) it seemed desirable to obtain data on the nature of the wood boring activity of the organism, as well as the quantity of wood so consumed per 24 hours. Blocks of wood containing the specimens were put into standing sea water, prior to the running of the toxicity tests.

It had been desired to collect and weigh the wood borings before, during, and after exposure as a measure of boring activity. This was done with a few blocks, enough to show that the amount of boring is roughly proportional to the number of siphons extruded.

Borings were collected on weighed filter papers, at 24-hour periods, brought to as nearly constant weight as possible in desiccators, and weighed. A drying oven would have facilitated the process and made possible the collection of borings on all the blocks instead of the few that were done.

NO. PAIRS OF SIPHONS EXTRUDED	WEIGHT OF BORINGS	BORINGS PER PAIR OF SIPHONS/24 HR.
116	5.68 gms.	.048 gms.
94	2.91 gms.	.031 gms.
57	1.73 gms.	.030 gms.
57	.70 gms.	.012 gms.
23	.98 gms.	.042 gms.
67	5.10 gms.	.076 gms.
75	3.20 gms.	.042 gms.
29	2.40 gms.	.083 gms.
123	5.10 gms.	.041 gms.
72	3.20 gms.	.044 gms.
56	4.60 gms.	.082 gms.
52	3.80 gms.	.073 gms.
	Average	.050 gms.

This would indicate that the average weight of wood excavated per *Bankia* per day is of the order of 0.05 grams. While too much weight should not be placed on these figures, the results are remarkably uniform considering the conditions.

During exposure to toxic solutions, no boring was carried on. The only material ejected was a small amount of amorphous black substance, differing from the light brown or yellow wood borings.

IV. CONCLUSIONS

1. The toxicity of the various compounds is approximately the same for *Limnoria,* exposed *Bankia,* and *Bankia* embryos.
2. As might be expected, *Bankia* incased in wood in its natural burrow is more resistant than when removed and exposed to the toxic agents.
3. The materials which show marked toxicity on the exposed *Bankia* are also toxic to the borer incased in wood although a longer time is required to produce the lethal effect.
4. In the exposed *Bankia* death appeared to be coincident with the absence of response to the stimulus of the teasing needle and with one exception no revival occurred on transference to fresh sea water.
5. Indications are that during exposure to the action of any toxic, the wood-boring activities of *Bankia* are greatly decreased.
6. Methyl orange, congo red, litmus, neutral red, and phenolphthalein when used as indicators to determine the acidity or alkalinity of the digestive tract of *Bankia* showed no color changes as solutions or in contents cells of the caeca. Any reaction is probably so slight as to be indeterminable.
7. Four and six-tenths parts sodium chloride per thousand is the lowest salinity to which *Bankia* may be exposed and recover. Death occurred at a salinity of 4.0 parts per thousand and below.
8. Of 45 compounds tested, the following had the best general toxic value against both the teredine and crustacean type of borer, in the order named:

   Chlorvinyl arsenious oxide
   Phenyl arsenious oxide
   Mercuric oxide
   Mercuric chloride
   Mercuric arsenate
   Cuprous cyanide
   Cupric orthonitrobenzoate.
   Cuprous chloride
   Mercuric anilinate
   Mercuric benzoate
   Crystal violet

V. RECOMMENDATIONS

It is recommended that toxicity tests can be completed on compounds that have been tested in less than the four ways described in this report.

It is suggested further that the same tests be conducted on various coal tar and water gas creosotes and creosote fractions as well as on fuel oil and any other substances which might be used as carriers for toxics in service tests. The tests should also be conducted on other compounds such as arsenic chloride, arsenic, and arsenious oxides, antimony compounds, iodine,

picric acid and all materials included in the service test pieces exposed at Beaufort during the summer of 1923.

A series of chemotropic experiments should also be made under the microscope using high dilutions of toxic solutions in capillary tubes and measuring their possible repellant action on freely swimming embryos. There are a number of substances which are not necessarily toxic but which might have a marked repellant effect. (8)

Efforts should be made to contrive some method of testing compounds not soluble at 1-100,000 parts sea water. These compounds might be soluble in 1-1,000,000 parts sea water, in which case they could be tested on vigorously swimming embryos for comparatively long periods of time. Or a minute quantity of the insoluble material might be introduced into a watch crystal containing embryos swimming in sea water and any repellant effect observed.

Although the tests made on caeca seem conclusive that the reaction of the digestive tract is a negligible factor from a toxicity standpoint, the problem might be attacked again using a very large number of caeca and other indicators. At the same time that the caeca were being removed the livers could also be collected and the attempt made to confirm Harington's experiments on cellulose-splitting enzymes in the liver. (8) The attempt should again be made to raise the embryos to the point of attachment to wood. Aside from biological considerations this is valuable from a toxicity standpoint as well in view of the very enlightening experiments that could be made upon the settling veliger.

The question of the reaction of the compounds in sea water should also be investigated.

The experiments upon the effect of reduced salinities on *Bankia gouldi* were of a preliminary nature and should be amplified, using sufficient material to establish a lethal salinity, and the same tests might well be made upon *Teredo sigerfoosi* and *Limnoria.*

VI. BIBLIOGRAPHY

1. **Sigerfoos**—Natural History, Organization and Late Development of the Teredinidae, Bull. U. S. Bureau Fish. 27.
2. **Blum**—On the Effect of Low Salinity on *Teredo navalis,* Univ. of Cal. Pub. in Zoology, Vol. 22, 4.
3. **Dore and Miller**—The Digestion of Wood by *Teredo navalis,* Univ. of Cal. Pub. in Zoology, Vol. 22, 7.
4. **Bartsch**—Monograph on the American Shipworms, Bull. 122, Smithsonian Institute.
5. **Walker and McQuaid** — Digest of Available Information on Marine Borers and Preliminary Recommendations Regarding Study of Methods of Prevention of Their Attack, Report, No. E.A.C.D. 247.
6. **Shackell**—Comparative Toxicity of Coal Tar Cresote Distillates and of Individual Constituents for the Marine Wood Borer, Xylotrya, Proc. of American Wood Preservers' Association, 1915.
7. **Shackell**—Marine Borers from the Wood Preservers' Standpoint, Proc. of American Wood Preservers' Association, 1916.
8. **Harington**—Third (Interim) Report of the Committee of the Institute of Civil Engineers, 1923.

APPENDIX II

Table of Contents

APPENDIX II

THE DESTRUCTION OF MARINE BORERS IN PILING BY THE ACTION OF CHLORINE GENERATED BY THE ELECTROLYSIS OF SEA WATER

August 17, 1923

By H. S. McQuaid

ABSTRACT

A process for the destruction of marine borers on piling, depending on the generation of chlorine around the piling by the electrolysis of sea water, has been investigated by the Chemical Warfare Service.

Teredo infested blocks of wood were immersed in a jar of sea water, and this was electrolyzed by passing D. C. current, using carbon and iron electrodes. The number of *Teredo* remaining immediately after the test and for varying number of hours thereafter was compared with the original number.

These tests show that this method of chlorine production has only a slight toxic effect on mature *Teredos*.

I. INTRODUCTION

The problem of protecting wooden marine structures against attack by marine borers, divides itself into two phases:

1—The impregnation of new lumber to resist attack by these sea worms.

2—The treatment of present marine structures to prevent further action.

The method discussed in this report applies only to the second phase, the protection of existing construction.

It is claimed that chlorine generated by the electrolysis of sea water in close proximity to piling has a toxic effect on the *Teredo* borers in the piling and also an inhibiting effect on the settling of embryo borers on the wood. Occasional treatment of the wooden structures by this method during the breeding season is claimed to keep the piling free from attack.

The word *Teredo* in this report is used in a general sense, to designate teredine borers. The actual species on which these tests were run was *Bankia gouldi.* These experiments were conducted by the Chemical Warfare Service, U. S. Army, at the laboratories of the Bureau of Fisheries, Beaufort, N. C.

II. THEORETICAL

The process is described as follows:

Carbon anodes are suspended in the sea water in proximity to the piling and are distributed evenly about the infested surface. Iron cathodes are then suspended sufficiently removed from the anodes to prevent the mixing

of the chlorine and caustic formed by the action. Each treatment should consist of 100 amperes direct current at approximately 20 volts per pile for one or two hours. Four treatments per season are recommended.

Assuming the average pile to be one foot in diameter, and the length exposed to *Teredo* attack to be 30 feet, the area to be treated will be 94.3 square feet. A current of 100 amperes will give 1.06 amperes per square foot of pile surface exposed. As one ampere hour generates 1.33 grams of chlorine, there will be 1.41 grams of chlorine generated per hour per square foot of pile surface exposed.

III. EXPERIMENTAL

A. First Procedure

1. **Apparatus**—*Teredo*-infested blocks 4 inches square were immersed in sea water to a depth of 12 inches in a large wooden tank. Four graphite anodes, ½-inch square x 2 feet long, were suspended around the block, one for the middle of each side, ⅛-inch from its surface and extending the length of the block. The four graphite rods were connected electrically to form the positive lead wire from the source of current. The cathode consisted of a 12-inch length of 1-inch iron pipe suspended in the sea water one foot away from the test block and anodes.

The direct current was supplied by dry cells connected in series in sufficient number to deliver the proper current to the anodes. The circuit was provided with a direct current ammeter and a voltmeter in order to keep the electrical conditions constant.

2. **Experimental Details**—Three tests were made following the outline given above.

The number of *Teredo* in each block was determined before the treatment with chlorine.* After the test, the blocks were put into fresh sea water and the number of siphons appearing were counted at time intervals until it was certain there was no delayed action of the chlorine.

In experiment No. 3, a 1-inch hole was bored through the center of the block, a single graphite anode was inserted, and the opening at the top filled in with putty to prevent the escape of chlorine. This was done in an attempt to secure a more uniform distribution of chlorine over the surface of the block.

The conditions of these experiments are given in Table I, and the results in Table II.

TABLE I

	Test No. 1	Test No. 2	Test No. 3
Block No.	38	40	37
Current—amperes	2	4	4
Voltage	5	10	15
Current per square foot of block surface	1.5 amps.	3.0 amps.	3.0 amps.
Chlorine liberated per hour per square foot of block surface	2.0 grams	4.0 grams	4.0 grams
Time—hours	2	3	4½

*The handling of the *Teredos* and the counts before and after the tests were the work of Miss Marjorie Allen, who was temporarily stationed at the Bureau of Fisheries Laboratory on the marine piling investigation.

TABLE II—EXPERIMENT 1

TEREDO COUNT BEFORE TEST:	18 Days	15 Days	14 Days	13 Days	12 Days	11 Days	10 Days	6 Days	5 Days	4 Days	1 Hour
1st side..	8	9	10	9	10	...	...	...	...	...	10
2nd side..	94	117	90	96	97	95	90	114	106	107	75
3rd side..	6	12	11	10	11	...	...	...	...	...	13
Total ..	108	138	111	115	118	...	...	...	...	...	98

AFTER TEST:	1 Hour	4 Hours	1 Day	2 Days	3 Days	4 Days	6 Days	7 Days
1st side.......	1	8	8	10	6	12	5	11
2nd side.......	37	40	85	71	50	79	53	58
3rd side.......	13	16	9	14	14	14	10	10
Total	51	64	102	95	70	105	68	79

EXPERIMENT 2

TEREDO COUNT BEFORE TEST:	13 Days	12 Days	11 Days	7 Days	6 Days	5 Days	1 Hour
1st side........	114	126	97	57	82	78	66
2nd side........	...	...	...	...	...	...	10
Total	...	...	..	...	...	...	76

AFTER TEST:	1 Hour	1 Day	2 Days	3 Days	4 Days	6 Days	7 Days
1st side........	30	65	79	69	63	39	55
2nd side........	10	10	8	3	5	10	5
Total	40	75	87	72	68	49	60

EXPERIMENT 3

TEREDO COUNT BEFORE TEST:	12 Days	11 Days	10 Days	9 Days	8 Days	1 Hour*
1st side...........	12	7	7	8	16	10
2nd side...........	22	16	19	28	38	28
3rd side...........	44	45	30	21	69	42
Total	78	68	56	57	123	80

*After boring hole in block.

AFTER TEST:	1 Hour	1 Day	2 Days	4 Days	5 Days
1st side.............	6	3	4	6	9
2nd side.............	24	20	20	8	28
3rd side.............	18	25	27	12	28
Total	48	48	51	26	65

B. Second Procedure

In order to get more positive information on the action of chlorine on *Teredos,* a different procedure was followed. The anode and cathode compartments of the electrolysis apparatus were separate jars of about six liters capacity and connected by a glass siphon filled with sea water. Time of electrolysis was 4½ hours, at a current of 2 amperes.

Test No. 4. The *Teredo* were excavated from their burrows, care being taken to preserve them intact, and placed in the anode compartment while electrolysis of sea water was taking place. The following results were obtained:

Control—5 out of 5 alive after 18 hours.

Anode—3 out of 5 alive after 18 hours.

Test No. 5. *Limnoria* were placed in both anode and cathode compartments while electrolysis was taking place.

Control—5 out of 5 alive after 23 hours.

Anode—3 out of 5 alive after 23 hours.

Cathode—5 out of 5 alive after 23 hours.

Observation has shown that the *Teredo* pulls in his siphons and closes up his burrows with his pallets very soon after the start of the chlorine generation. The burrows are kept closed throughout the test, but the siphons are extended again a short time after being placed in fresh sea water.

IV. CONCLUSIONS

The results of these tests show that chlorine as generated and used in this process has only a slight toxic effect on mature *Teredos.*

APPENDIX III

Table of Contents

APPENDIX III

PRESERVATION OF NEW WOODEN STRUCTURES FROM ATTACK BY MARINE BORERS

January 8, 1924

By H. S. McQuaid

ABSTRACT

In the course of an investigation on the protection of marine structures against wood-boring organisms, a number of toxic substances were used to impregnate sections of railroad ties at Edgewood Arsenal which were then exposed to the attack of marine borers in the harbor at Beaufort, N. C., during the summer of 1923.

Some experimental work was conducted to determine the best method of impregnation for given substances, and four adaptations of standard methods were selected. Experiments were conducted to develop suitable impregnating mediums for different solid toxics. Satisfactory impregnation was secured in practically all cases.

The toxics used include general substances known or claimed to be toxic to other forms of life, and in addition, certain chemical warfare compounds with favorable physical characteristics. Some of the impregnations were made and the exposures started before the systematic study of the toxicity of compounds to marine organisms was completed, so that many of the substances used were selected more or less at random. Of the substances tested, all showed some protection when compared with control blocks.

A study of the cost of impregnation of various toxics was made.

Acknowledgments are made for the cooperation of Mr. Chas. H. Hatsel, of the Bureau of Fisheries, and Mr. R. S. Perry, Jr., Chemist in Charge of the laboratory work of the Bureau of Construction and Repair, U. S. N., at Beaufort, N. C.

I. INTRODUCTION

This report describes the experimental work of the Chemical Warfare Service in connection with the service tests on wood impregnated with various toxics and exposed to the attack of marine borers. It is in the nature of a progress report dealing with the test conducted since undertaking the investigation.

The plan adopted was to treat short blocks of wood with a variety of materials in experimental impregnation apparatus at Edgewood Arsenal. Small blocks, 2¾ inches square by 12 inches long, were cut from oak and white pine railroad ties, and were seasoned in the laboratory before impregnation. Several methods of treatment were employed depending on the impregnant used. These blocks were then exposed to attack of shipworm and *Limnoria* in Beaufort Harbor, Beaufort, N. C. Untreated blocks were

exposed for comparison. All were regularly inspected from time to time, and in four to six months were removed for thorough examination.

II. METHODS OF CONDUCTING TESTS

A. Methods of Impregnation

In impregnating the test blocks with the various toxics, four methods of impregnation were used:

Vacuum, temperature, and pressure process.
Boiling or open tank process.
Vacuum and pressure process.
Straight vacuum process.

In the vacuum temperature and pressure process, the seasoned wooden blocks are put into an iron cylinder supplied with a steam coil. A vacuum of 28 inches is drawn on the cylinder and maintained for three hours. The cylinder is then filled with impregnating liquid which has been previously heated to about 65° C. Pressure is applied to the liquid in the cylinder by means of a hand force pump until it reaches a pressure of 175-200 pounds per square inch and this pressure is maintained along with a temperature of 65° C. for three hours. The pressure is then released, the cylinder emptied, and the wooden blocks taken out. The accompanying photograph (Fig. 34), shows the arrangement of the equipment used in this process. The lower cylinder is the impregnation cylinder and is supplied with vacuum, pressure, and a steam coil. The upper cylinder is the storage and heating tank for the impregnating liquid.

In the boiling process, a wooden block is put into an open top iron cylinder and covered over with the impregnating vehicle. Then the contents of the cylinder are heated up to about 150° C. for three hours and the wood is removed and immediately plunged into a cylinder, containing the impregnating liquid at room temperature, where it is allowed to remain over night.

In the vacuum and pressure process, the wood is placed in a closed cylinder and a vacuum of 28 inches of mercury applied for three hours. Then the cylinder is filled with impregnating liquid and a pressure of 40 pounds per square inch is put on the cylinder for three hours.

When the straight vacuum process was used, the block was put into a vacuum cylinder, the air exhausted in the cylinder and block, and the impregnant run in to cover the block of wood. After standing for 30 minutes to 3 hours, the solution was run out and the piece removed.

The boiling or open tank process was used wherever possible, since a minimum amount of impregnating liquid can be used and very good impregnations may be effected. The vacuum and pressure process was used on all water and solvent solutions, especially ammoniacal solutions, where heating was detrimental and the boiling temperature was too low for the open tank method.

All four of these methods are adaptations of standard large scale impregnating practice and it is believed that even better penetration could be secured on a large scale than was obtained on the small blocks.

B. Method of Exposure

Every toxic impregnation was made at least in duplicate so that one block could be sheathed with a ½-inch thickness of untreated wood while the other block was directly exposed. This was for the purpose of determin-

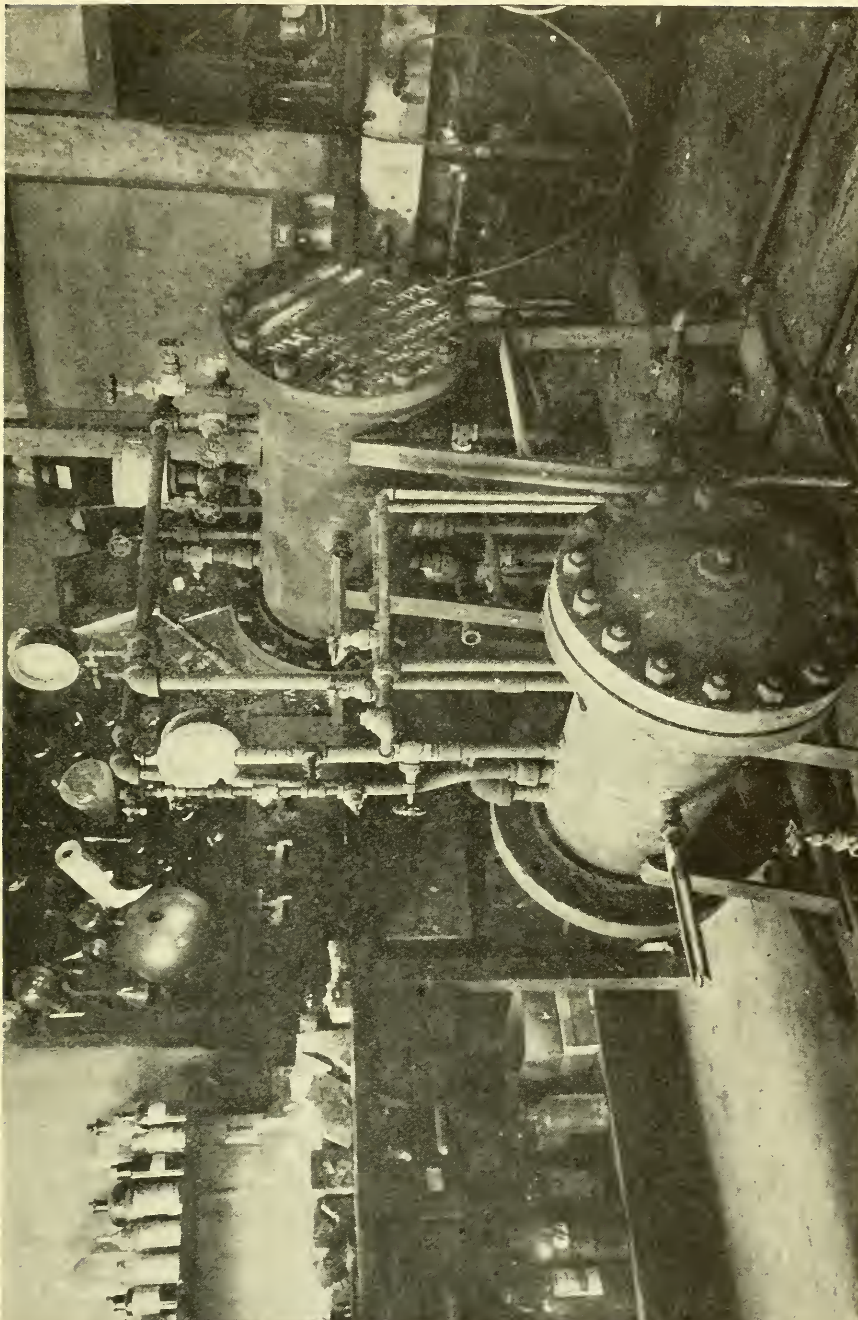


FIG. 34—"SMALL SCALE" VACUUM-PRESSURE IMPREGNATING APPARATUS

ing whether the various toxics acted on the mature *Teredos* in the same manner as on the embryo *Teredos.*

The test pieces were exposed in the following manner. There is a test rack in the form of a small skeleton pier in the 300-foot channel which runs north and south between the eastern shore of the town of Beaufort and Pivers Island, where the Bureau of Fisheries laboratory is situated. The rack is approximately 600 feet long and 30 feet wide, consisting of three rows of piling, the piles being spaced 20 feet apart longitudinally and 15 feet laterally, and runs north and south, parallel to the shore. The water has a depth of about five feet at low tide at the inner row of piles. A cable was strung from the southern and along the inner four sections of the rack in such a position that it was practically level with the water at low tide, and the pieces were attached to the cable with galvanized iron wire by means of a screw eye in the end of each piece. The blocks were spaced about four inches apart and an untreated control block was placed at intervals of every ten or less test pieces. It was not known whether the fact that the blocks were allowed to swing on the cable would have any effect on the intensity of marine borer attack, but the severe attack indicated on the blank control pieces proved that this was not a factor, and incidentally showed that the toxic area created by the vicinity of impregnated pieces was not sufficiently great to have any noticeable effect on the intensity of attack on the unimpregnated controls.

C. Sheathing

When the first test pieces were put into the water, every alternate piece was completely encased in a closed box ½-inch thick. This method proved unsatisfactory due to swelling of the outside container away from the encased test piece. This produced spaces between the test pieces and the sheathing too great for a *Teredo* to span.

The above method was modified on later pieces by having the sheathing screwed directly to the sides of the test pieces. This proved unsatisfactory due to swelling, splitting, and warping of the casing caused by a lack of allowance for expansion.

Finally, all previous sheathings were removed and each test block was sheathed on two sides with a board ½-inch thick nailed to the test piece. This proved quite satisfactory and the presence of exposed toxic surfaces close by had no effect on the entrance of *Teredos* into the sheathing.

D. Inspection of Test Pieces

Inspections of all the test pieces in the water at those times were made on July, 9, 1923, July 21, 1923, August 15, 1923, and November 27, 1923, which probably marks the close of the *Teredo* breeding season. The inspection consisted in examining the test samples for attack and the sheathed pieces for attack underneath the sheathing. In the final examination, all pieces which showed the slightest evidence of attack were split open and carefully inspected, note being made of the extent of damage, faulty impregnation, etc.

III. MATERIALS USED

A. Wood Samples

All the samples of wood used for the test pieces were cut from white pine railroad ties supplied by the Pennsylvania Railroad Company, except in one

series (Series No. 40) in which the blocks were cut from oak ties obtained from the same source. The ties were partly seasoned. The blocks were stored in an electric oven at 55° C. for about two weeks before being used. As a result the wood was quite dry when treated with the various impregnating materials.

B. Toxics

1. **Aczol**—This was a commercial wood preserving compound stated to consist of 8.5 per cent ammonia, 2 per cent zinc, 2 per cent copper, and 7.5 per cent carbolic acid. It is used in the ratio of 12 parts of aczol to 100 parts of water.

2. **Cupric Oxide**—This material was dissolved in strong ammonia to saturation and then diluted to 10 per cent ammonia with water.

3. **Cupric Carbonate**—(Chandler Patent, U. S. No. 1,388,513). This solution was made up by mixing a concentrated solution of copper sulphate with a solution of 8.5 per cent sodium carbonate and 1.5 per cent sodium bicarbonate, so that the resulting solution contained 0.6 per cent of copper sulphate. This solution, after standing from 2 to 24 hours, precipitated insoluble crystals of cupric sodium carbonate. If the wood was impregnated with this material inside of 2 hours after the making up of the solution, the insoluble copper salt was precipitated in the pores of the wood.

4. **Copper Stearate in Carbon Tetrachloride**—Copper stearate was formed by precipitating a solution of sodium stearate with copper sulphate solution. After washing and drying, it was dissolved in carbon tetrachloride.

5. **Cupric Carbonate**—This material was precipitated in the wood by impregnating with a 5 per cent solution of copper sulphate, drying and following with an impregnation of 5 per cent sodium carbonate solution.

6. **Cupric Arsenite in Ammonia Solution**—Cupric arsenite was dissolved to saturation in strong ammonia solution, then diluted to 8 per cent ammonia solution with water.

7. **Cupric Ferricyanide in Ammonia Solution**—It was made up in the same manner as copper arsenite.

8-9. **Mercury Stearate in Paraffine**—Both ingredients were heated until they were melted and stirred together.

10. **Cupric Hydroxide in Ammonia Solution**—The cupric hydroxide was dissolved to saturation in strong ammonia water and then diluted to 8 per cent ammonia.

11. **Rubber in Benzene**—Ceylon crêpe rubber was cut into small squares and dissolved in benzene.

12. **Crystal Violet and Copper Tannate**—The wood was impregnated with a solution of crystal violet and copper acetate. After drying, it was again impregnated with a 5 per cent tannic acid solution to mordant the dye.

13. **Ferric Ferricyanide**—This compound was formed from a mixed solution of sodium ferricyanide and ferric chloride.

14. **Newport Direct Sky Blue**—The dye was dissolved in a 2 per cent sodium carbonate solution.

15. **Newport Direct Black R.W.**—Same as for direct sky blue.

16. **Copper**—The wood was studded with small pieces of 16 gauge copper wire on ¼-inch center over its entire surface, or ordinary copper carpet tacks were nailed on ⅜-inch centers over the entire surface.

17. **Creosote**—The creosote had the following characteristics:
1.0 per cent water.
0.18 per cent residue insoluble in benzene.
Density at 38° C.—1.117.
Cut at 210° C.—2.5 per cent.
Cut at 210-235° C.—4.5 per cent.
Cut at 235-315° C.—19.0 per cent—density at 38° C.—1.05.
Cut at 315-355° C.—18.5 per cent—density at 38° C.—1.12.
Cut above 355° C.—54.5 per cent.
Coke residue—8.3 per cent.

18. **Copper Resinate in Creosote**—Copper resinate was prepared by saponifying resin with caustic soda and precipitating with copper sulphate solution. It was washed, dried, and dissolved in hot creosote.

19. **Diphenylaminechlorarsine (D.M.) in Creosote**—The diphenylaminechlorarsine was dissolved in the creosote.

20. **Cupric Orthonitrobenzoate in Creosote**—The salt was dissolved in the creosote.

21. **Barium Phenocresylate in Creosote**—A product called "Toxall" from Toch Brothers, dissolved in creosote.

22. **Copper and Mercury Soaps in Pine Tar Oil**—These test blocks were furnished by a commercial company.

23. **Copper Benzoate in Creosote**—The salt was dissolved in the creosote.

24. **Mercuric Benzoate in Creosote**—The salt was dissolved in creosote.

25. **Diphenylarsenious Oxide (D.A. oxide) in Creosote**—The diphenylarsenious oxide was dissolved in heated creosote.

26. **Mercuric Resinate in Creosote**—Prepared in the same manner as in No. 18.

27. **Chlorinated Cellulose**—The wood was evacuated and then treated a number of times with chlorine gas with a vacuum treatment between each gassing.

28. **Rubber Latex**—This is the colloidal suspension of rubber in water as it comes from the rubber tree. It contains about 38 per cent rubber and a little ammonia to preserve the colloidal condition.

29. **Copper Resinate in Creosote**—Same as No. 18.

30-33. **Sulphur**—The wood was impregnated with melted sulphur. The samples were furnished by the Union Sulphur Co., 33 Rector Street, New York City.

34. **Copper Stearate in Benzene Rubber Solution**—The copper stearate was dissolved in benzene and mixed with the benzene rubber solution.

35. **Mercuric Stearate in Creosote**—Prepared in the same manner as No. 18.

36. **Copper Hydroxide in Rubber Latex**—The copper hydroxide was dissolved in ammonia solution mixed with the rubber latex solution.

37. **Copper Stearate in Creosote**—Prepared similarly to No. 18.

38. **Mercury Anilinate in Creosote**—Mercury anilinate was prepared by treating aniline in water with mercuric chloride solution precipitating mercury anilinate.

39. **Mercuric Stearate in Benzene Rubber Solution**—Same as in No. 34.

40. **Methylene Blue and Copper Tannate**—Oak wood was impregnated with a 1 per cent methylene blue solution and after drying it was impregnated again with a saturated solution of copper acetate, which probably combined with the tannic acid in the wood to form insoluble copper tannate.

41. **Rubber Latex Vulcanized**—The wood was impregnated with rubber latex dried and treated with sulphur chloride solution to vulcanize the rubber.

42. **Petroleum Fuel Oil**—Commercial fuel oil.

43. **Mercury Resinate in Fuel Oil**—The mercury resinate was dissolved in the fuel oil.

44. **Copper Resinate in Fuel Oil**—Same method of preparation as in No. 43.

45. **Chlorinated Paraffine in Carbon Tetrachloride**—Paraffine was chlorinated to 60 per cent chlorine content and dissolved in carbon tetrachloride.

46. **Diphenylarsenious Oxide (D.A. oxide) in Fuel Oil**—The diphenylarsenious oxide was dissolved in the fuel oil.

47. **Diphenylaminechlorarsine (D.M.) Paraffine Solution**—Diphenylaminechlorarsine was dissolved in the liquid used in No. 45, chlorinated paraffine and carbon tetrachloride.

48. **Diphenylchlorarsine in Fuel Oil**—Diphenylchlorarsine was dissolved in the fuel oil.

49. **Phenylarsenious Oxide in Carbon Tetrachloride**—The phenylarsenious oxide was dissolved in the solvent.

50. **Diphenylchlorarsine (D.A.) in Paraffine**—The diphenylchlorarsine was dissolved in the melted paraffine.

51. **Phenylarsenious Oxide in Creosote**—Phenylchlorarsine oxide was dissolved in hot creosote.

52. **Diphenylchlorarsine in Creosote**—The material was dissolved in creosote.

53. **Silica Gel**—The wood was impregnated with a mixed solution of equal volumes of 10 per cent solutions of sodium silicate and hydrochloric acid and the solution was allowed to get into the pores of the wood, thereby impregnating the wood with silica.

IV. EXPERIMENTAL DATA

A. Explanation of Table

The table which follows summarizes the experimental data obtained on the exposure tests made at Beaufort, N. C., during the summer of 1923. The materials used, the methods of impregnation, and the method of exposure have been described. The results of these exposure tests are given in Table I. It will be recalled from previous descriptions that all blocks used in these tests were white pine, with the exception of Test No. 40, in which an oak block was used.

The following is an explanation of expressions used in this table:

1. Method of Impregnation

A refers to the vacuum, temperature and pressure process.
B refers to the straight vacuum process.
C refers to the vacuum and pressure process.
D refers to the boiling or open tank process.

2. Condition of Samples—The condition of the blocks after exposure is described either as "O. K.," or attacked. By "O. K." is meant that no shipworm or *Limnoria* attacks were made on the block. In the other case, the attack may be slight or serious, as noted. Where the expression (1) appears, it indicates that the attack was limited to *Limnoria*.

3. Impregnating Costs—The table lists only the material costs on the toxics tested. As practically all the materials in practice would be impregnated into the wood by means of the present day methods, total costs can be obtained by adding a charge for impregnating to the materials costs given.

The following costs are given on creosoted piling (Weiss, "The Preservation of Structural Timber," pp. 185-186):

Forty-foot pile treated to 16 pounds per cubic foot and driven in place cost $14.75 per pile.

With a treatment of 22 pounds per cubic foot, the cost is $16.50 per pile.

This is based on the cost of peeling per cubic foot—1 to 2½c.

With preservatives at 9c per gallon (8¾ pounds) and a treatment of 16 pounds per cubic foot, the cost of treatment per cubic foot is 3½ to 6c.

In Nos. 5, 12, 40 and 41, the impregnation costs must be doubled because they make use of a double impregnation.

In Nos. 4, 11, 34, 39, 45, 47 and 49, the material costs should be credited with a certain percentage of solvent recovery for which they have not been credited.

B. Observations

1. Cupric Oxide Impregnation—No. 2 received a poor impregnation.

2. Dye Impregnation—Nos. 12, 14 and 15, (dyed pieces) showed little or no penetration of dye, but good penetration of water. This showed that the wood fiber took out most of the dye at the surface of the wood and allowed very little to penetrate into the interior. Nos. 14 and 15 gave protection until the color bleached out and then they were attacked by *Teredos*.

3. Mercury Stearate Impregnation—No. 8 received a rather poor impregnation on account of the decomposition of the mercury stearate, due

to continued heating. This showed that the mercury soaps cannot stand high temperatures for any length of time.

4. **Creosote Impregnation**—No. 17-1, the attacked creosote piece as shown in the photographs, Nos. 3819, 3820, received a faulty impregnation, as a strata throughout the length of one corner received no creosote. The *Teredo* attacked the piece in this unimpregnated portion, which was all heart wood.

5. **Rubber Latex Impregnation**—In the rubber latex impregnations, some of the latex enters the wood, but a portion is filtered out by the wood and forms a thick viscous layer on the surface.

6. **Chlorinated Cellulose**—No. 27. The fact that the test pieces treated with chlorine were missing indicates that the action of chlorine impaired the mechanical properties of the wood and made it rather soft and friable. It is quite possible these pieces were in such poor mechanical condition that they were pulled off the hooks by the mere action of the water.

7. **Sulphur Impregnation**—The sulphur impregnated pieces disclosed *Teredos* of a greater size than in any of the others, although the number was not so great as in the untreated pieces.

8. **Control Blocks**—In general, in comparison with the untreated bait pieces, all the impregnated pieces showed at least some deterrent action to marine borer attack. In no case were any of the treated pieces as badly attacked as the bait pieces.

In addition to the compounds in Table I, a test was made using "Paravar Varnish," a commercial compound supplied by one of the large rubber companies. This is said to be a self-curing rubber cement in which benzine is used as the vehicle. It was originally suggested for use as protection for concrete marine structures, and in this connection was claimed to have a decided penetrative effect. A test piece painted with eight coats of the material was exposed at Beaufort with the first pieces sent down. At the first inspection, the piece seemed unattacked, but at the final examination, the piece was as badly attacked as the unimpregnated control pieces. This indicates that so long as the material remains intact as a surface coat, it probably gives protection, but just as soon as the coat becomes at all imperfect, due to the action of the sea water, the protection is negative. The conclusion is, that applied in this way, Paravar is useless as a preservative for marine piling.

The accompanying photograph (Fig. 35) shows a longitudinal cross section of several of the test pieces after exposure. As will be noted, block No. 4 in this photograph is a straight creosote impregnation showing streaky impregnation in the heart wood, and slight *Teredo* attacks in this portion. Details of this piece are shown in the photograph (Fig. 36).

C. Discussion of Data

1. **Cost of Impregnation**—On account of the differences in degrees of impregnation of the test pieces, the most logical method of comparing costs upon the different materials used would be to figure all costs upon an equal degree of impregnation. In the following table this has been done. An average figure of 20 pounds of preservative per cubic foot of piling was

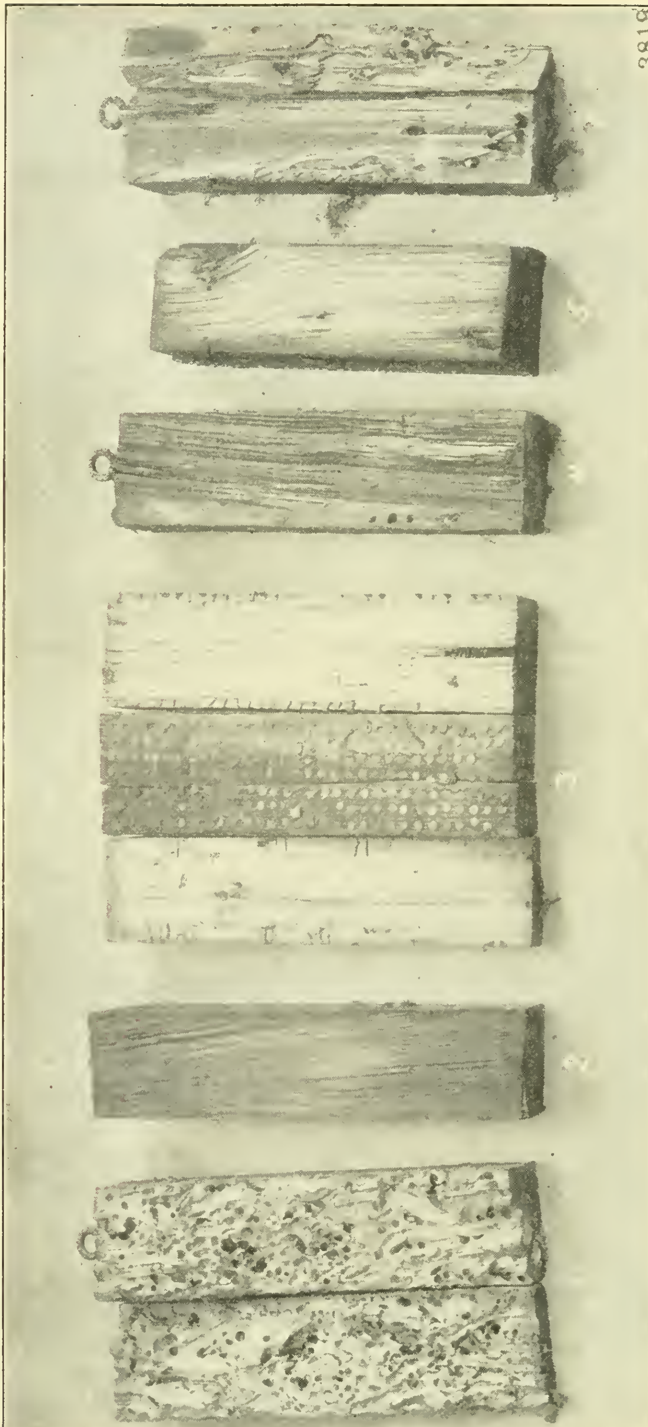


FIG. 35—DETAILS OF SECTIONS OF TEST PIECES AFTER EXPOSURE (ONE-FIFTH ACTUAL SIZE)

1—Blank—no impregnant used.
2—Aczol impregnation.
3—Copper studded pieces.
4—Straight creosote impregnation.
5—Crystal violet.
6—Sulphur impregnation.

taken. The material costs of the toxics are the same as those used in Table I, and are based on current prices.

On costs on No. 4, an 80 per cent yield on solvent recovery is assumed.

On Nos. 36 and 41, an average figure of 5 pounds of preservative per cubic foot of piling is used instead of 20 pounds, as rubber latex is more difficult to use as an impregnant. No costs are given for No. 21, as the preservative was not prepared here.

No. 6, labor cost, is low, and is figured on the possible use of an air pressure gun, or some similar means for imbedding the copper particles in the wood.

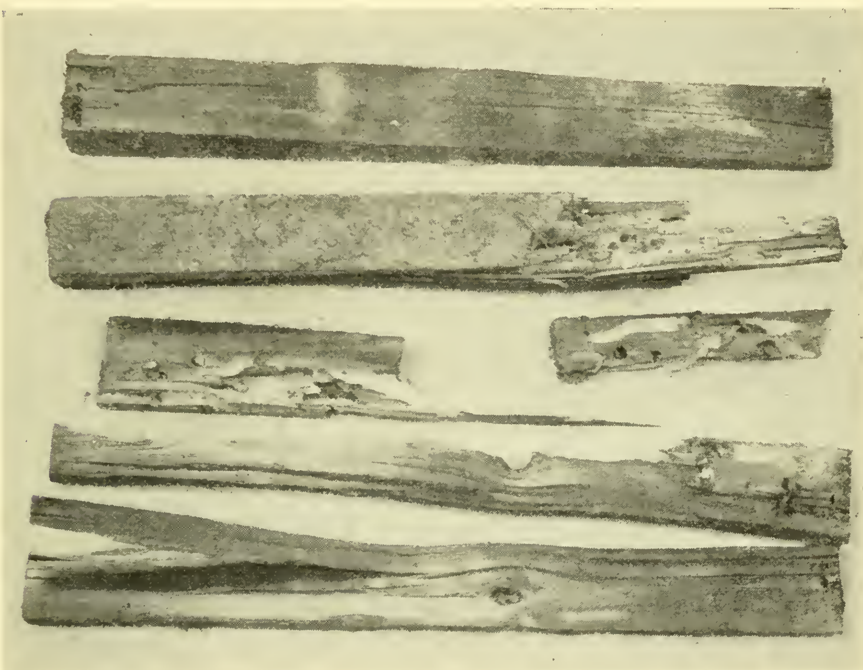


FIG. 36—DETAIL OF ATTACK ON CREOSOTED TEST PIECE

2. **Toxicity of Impregnants Tested**—While Table II gives a rough estimate of relative costs, they are by no means final. The primary purpose of these tests was to distinguish between toxic and non-toxic compounds. Consequently, a high percentage of toxic compound was used in most instances, even though it is quite possible that a smaller quantity would be equally effective. In the creosote impregnations, most of the mixtures were made with a 5 per cent toxic content. With the more expensive toxics, like diphenylaminechlorarsine, diphenylchlorarsine, and their oxides, a 5 per cent content would render the preservative very expensive. But, on account of their high toxic qualities, it is quite likely that a percentage much less than 5 per cent would produce lethal effect. In these cases, the price of the preservative would approach that of the preservatives containing cheaper but less toxic compounds.

TABLE I

Serial Number	Number	Toxic Used	Vehicle Used	% Weight of Toxic in Vehicle	Method of Impregnation	Weight of Wood	Weight of Wood After Impregnation	Weight of Impregnant	% Weight of Impregnant in Wood	Lbs. of Impregnant per Cu. Ft. of Wood	Lbs. of Impregnant per Sq. Ft.	Cost per Pound of Toxic	Cost per Pound of Vehicle	Total Material Cost of Impregnant per Lb.	Cost of Impregnant per Sq. Ft.	Date Exposed	Days Exposed	Condition of Samples
1	1	Aczol..........	Water Solution..	2.4	A	570 g.	1350 g.	780 g.	57.8	32.8	1.88	....	....	....	....	6/ 7/23	Still exposed	O.K.
1	2	Aczol..........	Water Solution..	2.4	A	570 g.	1270 g.	700 g.	55.1	29.4	1.68	....	....	....	....	6/ 7/23	172	O.K.
	3	Aczol..........	Water Solution..	2.4	A	587 g.	1400 g.	813 g.	58.0	34.2	1.96	....	....	....	....	6/ 7/23	172	O.K.
	4	Aczol..........	Water Solution..	2.4	A	510 g.	1450 g.	940 g.	64.8	39.5	2.26	....	....	....	....	6/ 7/23	172	O.K.
	5	Aczol..........	Water Solution..	2.4	A	510 g.	1470 g.	960 g.	65.4	40.3	2.31	....	....	....	....	6/ 7/23	172	O.K.
2	1	Copper Oxide...	10% Ammonia Solution	0.4	A	540 g.	1270 g.	730 g.	57.5	30.7	1.76	$0.18	$0.05	$0.051	$0.0898	6/ 7/23	172	One corner (1)
	2	Copper Oxide...	"	0.4	A	545 g.	1250 g.	705 g.	56.4	29.6	1.69	....	....	....	0.0862	6/ 7/23	172	attacked (1)
	3	Copper Oxide...	"	0.4	A	550 g.	910 g.	360 g.	39.6	15.1	0.865	....	....	....	0.041	6/ 7 23	172	attacked (1)
	4	Copper Oxide...	"	0.4	A	550 g.	920 g.	370 g.	40.2	15.5	0.890	....	....	....	0.0454	6/ 7/23	172	attacked (1)
	5	Copper Oxide...	"	0.4	A	550 g.	860 g.	310 g.	36.0	13.0	0.745	....	....	....	0.0380	6/ 7/23	172	slight attack
3	1	Copper Carbonate (Chandler)	Mixed Solution {$CuSO_4$, Na_2CO_3, $NaHCO_3$}	0.74	A	563 g.	1455 g.	892 g.	60.6	37.5	2.15	....	....	0.003	0.00645	6/ 7/23	172	attacked (1)
	2	"	"	0.74	A	570 g.	1400 g.	830 g.	59.3	34.8	1.99	....	....	....	0.00597	6/ 7/23	172	attacked (1)
4	1	Copper Stearate.	CCl_4..........	2.0	B	....	....	....	....	....	.....	0.17	0.10	0.103	....	6/ 7/23	172	O.K.
5	1	Copper Carbonate	Double Impregnation {5% $CuSO_4$, 5% Na_2CO_3}	3.86	A	621 g.	956 g.	335 g.	35.1	14.1	0.808	0.08	....	0.08	0.0646	6/18/23	161	O.K.
	2	"	"	3.86	A	552 g.	1161 g.	609 g.	52.4	25.6	1.47	....	....	....	0.1180	6/18/23	161	O.K.
6	1	Copper Arsenite.	8% Ammonia Solution	3.0	C	495 g.	1348 g.	853 g.	63.3	35.8	2.05	0.28	0.04	0.048	0.0985	6/18/23	161	O.K.
	2	Copper Arsenite.	"	3.0	C	499 g.	1274 g.	775 g.	60.8	32.6	1.87	....	....	....	0.0897	6/18/23	161	O.K.
7	1	Copper Ferricyanide	8% Ammonia Solution	3.0	C	469 g.	908 g.	419 g.	46.2	17.6	1.01	0.25	0.04	0.0475	0.0480	6/18/23	161	attacked
	2	"	"	3.0	C	520 g.	884 g.	364 g.	41.2	15.3	0.876	....	....	....	0.0416	6/18/23	161	attacked
8	1	Mercury Stearate	Paraffine........	3 0	D	406 g.	562 g.	156 g.	27.8	6.6	0.378	0.45	0.03	0.0426	0.0161	6/18/23	161	attacked
	2	Mercury Stearate	Paraffine........	3 0	D	434 g.	538 g.	104 g.	19.4	4.4	0.252	....	....	....	0.0107	6/18/23	161	attacked
9	1	Mercury Stearate	Paraffine (Paraffine Oil Bath)	3 0	D	450 g.	747 g.	297 g.	39.8	12.5	0.716	0.45	0.03	0.0426	0.0305	6/18/23	161	O.K.
	2	Mercury Stearate	"	3.0	D	457 g.	651 g.	194 g.	29.8	8.1	0.465	....	....	....	0.0198	6/18/23	161	attacked
10	1	Copper Hydroxide	8% NH_3 Solution	2.5	C	476 g.	957 g.	481 g.	50.3	20.2	1.16	0.18	0.04	0.0435	0.0505	6/18/23	161	O.K.
	2	"	"	2.5	C	525 g.	1032 g.	507 g.	49.1	21.3	1.22	....	....	....	0.0530	6/18/23	161	O.K.

TABLE I (*Continued*)

Serial Number	Number	Toxic Used	Vehicle Used	% Weight of Toxic in Vehicle	Method of Impregnation	Weight of Wood	Weight of Wood After Impregnation	Weight of Impregnant	% of Impregnant in Wood	Lbs. of Impregnant per Cu. Ft. of Wood	Lbs. of Impregnant per Sq. Ft.	Cost per Pound of Toxic	Cost per Pound of Vehicle	Total Material Cost of Impregnant per Lb.	Cost of Impregnant per Sq. Ft.	Date Exposed	Days Exposed	Condition of Samples
11	1	Rubber.........	Benzene........	1.6	C	557 g.	735 g.	178 g.	24.2	7.5	0.43	0.30	0.036	0.041	0.0176	6/18/23	161	attacked
	2	Rubber.........	Benzene........	1.6	C	521 g.	845 g.	324 g.	38.4	13.6	0.78	....	....	....	0.032	6/18/23	161	attacked
12	1	Crystal Violet Copper Tannate	Water (Double Impregnation)	0.07	C	C.V.455g	790 g.	335gC.V.	42.4	14.1	0.808	C.V.2.10	....	....	0.00121			
				2.0C.T.	....	C.T.628g	740 g.	112gC.T.	15.1	4.7	0.27	C.T.0.45	....	0.0105	0.00243 0.00364	6/18/23	161	O.K.
	2	"	"	0.07	C	C.V.467g	809 g.	342gC.V.	42.3	14.4	0.825	....	....	....	0.00124			attacked through sheathing
				2.0C.T.	....	C.T.746g	906 g.	166gC.T.	18.3	6.97	0.40	....	....	....	0.00360 0.00484	6/18/23	161	
13	1	Ferric Ferricyanide	Water..........	1.34	D	827 g.	1542 g.	715 g.	46.4	30.0	1.72	0.20	....	0.0027	0.00465	6/18/23	67	attacked
	2	"	Water..........	1.34	D	1060 g.	1784 g.	724 g.	40.6	30.4	1.74	....	....	....	0.00470	6/18/23	67	attacked
14	1	Direct Blue.....	2% Na_2CO_3 Solution	1.0	D	466 g.	1030 g.	564 g.	54.8	23.7	1.36	0.50	0.0006	0.0056	0.00761	6/18/23	67	attacked
15	1	Direct Black....	2% Na_2CO_3 Solution	1.0	D	504 g.	645 g.	141 g.	21.8	5.9	0.338	0.50	0.0006	0.0056	0.00189	6/18/23	67	attacked
16	1	Copper.........	Studded........	....	....	450 g.	898 g.	448 g.	50.0	18.8	1.08	0.15	....	0.15	0.167	6/18/23	161	one teredo hole near knot
	2	Copper.........	Studded........	....	....	960 g.	1614 g.	654 g.	40.5	27.4	1.57	....	....	....	0.238	8/31/23	88	O.K.
17	1	Creosote........	....	....	D	780 g.	1480 g.	700 g.	47.3	29.4	1.68	0.024	....	0.024	0.0403	6/28/23	151	attacked
	2	Creosote........	....	....	D	1065 g.	1632 g.	567 g.	34.7	23.8	1.36	....	....	....	0.0326	6/28/23	151	lost
	3	Creosote........	....	....	D	800 g.	1400 g.	600 g.	42.9	18.0	1.03	....	....	....	0.0247	6/28/23	151	O.K.
18	1	Copper Resinate.	Creosote........	5	D	962 g.	1603 g.	641 g.	40.0	26.9	1.54	0.06	0.024	0.026	0.0400	6/28/23	151	O.K.
	2	Copper Resinate.	Creosote........	5	D	832 g.	1779 g.	947 g.	53.3	39.8	2.28	....	....	....	0.0593	6/28/23	151	O.K.
19	1	D. M..........	Creosote........	5	D	815 g.	1631 g.	816 g.	50.0	34.3	1.97	0.75	0.024	0.0603	0.1190	6/28/23	151	O.K.
	2	D. M..........	Creosote........	5	D	1101 g.	1844 g.	743 g.	40.3	31.2	1.79	....	....	....	0.1080	6/28/23	151	O.K.
	3	D. M..........	Creosote........	5	D	1018 g.	1694 g.	676 g.	39.9	28.4	1.63	....	....	....	0.0984	6/28/23	151	O.K.
20	1	Copper Onitrobenzoate	Creosote........	5	D	974 g.	1611 g.	637 g.	39.5	26.7	1.53	0.25	0.024	0.0353	0.0540	6/28/23	151	O.K.
	2	"	Creosote........	5	D	960 g.	1609 g.	649 g.	40.4	27.2	1.56	....	....	....	0.0551	6/28/23	151	O.K.
21	1	Barium Phenocresylate	Creosote........	1	D	576 g.	1155 g.	579 g.	50.1	24.3	1.39	....	0.024	....	....	6/28/23	151	O.K.
	2	(Toxall)........	Creosote........	1	D	882 g.	1436 g.	554 g.	38.6	23.3	1.34	....	....	....	....	6/28/23	151	O.K.

TABLE I (*Continued*)

Serial Number	Number	Toxic Used	Vehicle Used	% Weight of Toxic in Vehicle	Method of Impregnation	Weight of Wood	Weight of Wood After Impregnation	Weight of Impregnant	% Weight of Impregnant in Wood	Lbs. of Impregnant per Cu. Ft. of Wood	Lbs. of Impregnant per Sq. Ft.	Cost per Pound of Toxic	Cost per Pound of Vehicle	Total Material Cost of Impregnant per Lb.	Cost of Impregnant per Sq. Ft.	Date Exposed	Days Exposed	Condition of Samples
22	2	Copper and Mercury Soaps	Pine Tar Oil									0.30	0.045	0.051		6/28/23	151	missing
	4	"	Pine Tar Oil													6/28/23	151	O.K.
23	1	Copper Benzoate	Creosote	5	D	1064 g.	1583 g.	519 g.	32.8	21.8	1.25	0.76	0.024	0.061	0.0763	8/ 7/23	112	O.K.
	2	Copper Benzoate	Creosote	5	D	1005 g.	1706 g.	701 g.	41.1	29.4	1.68				0.1024	8/ 7/23	112	O.K.
	3	Copper Benzoate	Creosote	5	D	1065 g.	1747 g.	682 g.	39.1	28.6	1.64				0.1000	8/ 7/23	112	O.K.
24	1	Mercury Benzoate	Creosote	5	D	812 g.	1348 g.	536 g.	39.8	22.5	1.29	1.05	0.024	0.0753	0.0971	8/ 7/23	112	O.K.
	2	"	Creosote	5	D	1038 g.	1584 g.	546 g.	34.5	22.9	1.31				0.0986	8/ 7/23	112	O.K.
	3	"	Creosote	5	D	723 g.	1152 g.	429 g.	37.2	18.0	1.03				0.0775	8/ 7/23	112	O.K.
25	1	D. A. Oxide	Creosote	5	D	977 g.	1742 g.	765 g.	43.9	32.1	1.84	1.20	0.024	0.083	0.153	8/ 7/23	112	O.K.
	2	D. A. Oxide	Creosote	5	D	990 g.	1817 g.	827 g.	45.5	34.7	1.99				0.165	8/ 7/23	112	O.K.
	3	D. A. Oxide	Creosote	5	D	770 g.	1630 g.	860 g.	52.8	36.1	2.07				0.172	8/ 7/23	112	O.K.
26	1	Mercury Resinate	Creosote	5	D	788 g.	1329 g.	541 g.	40.8	22.7	1.30	0.47	0.024	0.0463	0.0601	8/ 7/23	112	O.K.
	2	Mercury Resinate	Creosote	5	D	800 g.	1453 g.	653 g.	44.9	27.4	1.57				0.0727	8/ 7/23	112	O.K.
	3	Mercury Resinate	Creosote	5	D	752 g.	1428 g.	676 g.	47.4	28.4	1.63				0.0755	8/ 7/23	112	O.K.
27	1	Chlorinated Cellulose			C	683 g.	722 g.	39 g.	5.4	1.6	0.092	0.03		0.03	0.00276	8/ 7/23	112	missing
	2	"			C	634 g.	652 g.	18 g.	2.8	0.76	0.043				0.00129	8/ 7/23	112	missing
28	1	Rubber	Latex	30	C	806 g.	1078 g.	272 g.	25.2	11.4	0.653	0.10		0.10	0.0653	8/ 7/23	112	attacked
	2	Rubber	Latex	30	C	817 g.	1170 g.	353 g.	30.2	14.8	0.85				0.0850	8/ 7/23	112	O.K.
29	1	Copper Resinate	Creosote	5	D	700 g.	1395 g.	695 g.	49.9	29.2	1.67	0.06	0.024	0.0258	0.0431	8/31/23	88	O.K.
	2	Copper Resinate	Creosote	5	D	714 g.	1395 g.	681 g.	48.9	28.6	1.64				0.0424	8/31/23	88	O.K.
	3	Copper Resinate	Creosote	5	D	858 g.	1283 g.	425 g.	33.2	17.9	1.03				0.0266	8/31/23	88	O.K.
30	1	Sulphur										0.015		0.015		8/ 7/23	112	attacked
	2	Sulphur							51.0							8/ 7/23	112	attacked
31	1	Sulphur										0.015		0.015		8/ 7/23	112	attacked
	2	Sulphur							42.2							8/ 7/23	112	attacked
	3	Sulphur							53.7							8/ 7/23	112	attacked
32	1	Sulphur										0.015		0.015		8/ 7/23	112	attacked
	2	Sulphur							16.7							8/ 7/23	112	attacked
	3	Sulphur							25.5							8/ 7/23	112	attacked
	4	Sulphur							24.8							8/ 7/23	112	attacked
33	1	Sulphur										0.015		0.015		8/ 7/23	112	attacked
	2	Sulphur							20.0							8/ 7/23	112	attacked

TABLE I (*Continued*)

Serial Number	Number	Toxic Used	Vehicle Used	% Weight of Toxic in Vehicle	Method of Impregnation	Weight of Wood	Weight of Wood After Impregnation	Weight of Impregnant	% Weight of Impregnant in Wood	Lbs. of Impregnant per Cu. Ft. of Wood	Lbs. of Impregnant per Sq. Ft.	Cost per Pound of Toxic	Cost per Pound of Vehicle	Total Material Cost of Impregnant per Lb.	Cost of Impregnant per Sq. Ft.	Date Exposed	Days Exposed	Condition of Samples
34	1	Copper Stearate.	1.6% Rubber in C_6H_6	2.0	C	761 g.	1151 g.	390 g.	33.9	16.4	0.9'0	0.17	0.035	0.0334	0.0361	8/31/23	88	attacked
	2	Copper Stearate.	"	2.0	C	909 g.	1433 g.	524 g.	36.6	22.0	1.26	....	....	....	0.0484	8/31/23	88	O.K.
	3	Copper Stearate.	"	2.0	C	958 g.	1356 g.	398 g.	29.4	16.7	0.957	....	....	....	0.0367	8/31/23	88	attacked
35	1	Mercuric Stearate	Creosote........	5.0	D	768 g.	1680 g.	912 g.	54.3	38.2	2.19	0.45	0.024	0.0453	0.0993	8/31/23	88	O.K.
	2	"	Creosote........	5.0	D	715 g.	1274 g.	559 g.	43.1	23.5	1.35	....	....	....	0.0611	8/31/23	88	O.K.
	3	"	Creosote........	5.0	D	718 g.	1520 g.	802 g.	52.8	33.7	1.93	....	....	....	0.0875	8/31/23	88	O.K.
36	1	Copper Hydroxide	4% NH_3 in 30% Rubber Latex	1.25	C	795 g.	1306 g.	511 g.	39.2	21.4	1.23	0.18	0.12	0.1223	0.1507	8/31/23	88	O.K.
	2	"	"	1.25	C	655 g.	1385 g.	730 g.	52.7	30.6	1.75	....	....	....	0.2140	8/31/23	88	O.K.
37	1	Copper Stearate.	Creosote........	5	D	879 g.	1722 g.	843 g.	49.0	35.4	2.03	0.17	0.024	0.0313	0.0635	8/31/23	88	O.K.
	2	Copper Stearate.	Creosote........	5	D	938 g.	1687 g.	749 g.	44.4	31.4	1.80	....	....	....	0.0564	8/31/23	88	O.K.
	3	Copper Stearate.	Creosote........	5	D	886 g.	1461 g.	575 g.	39.3	24.2	1.39	....	....	....	0.0135	8/31/23	88	O.K.
38	1	Mercuric Anilate.	Creosote........	5	D	1030 g.	2002 g.	972 g.	48.5	40.8	2.31	0.60	0.024	0.0528	0.1235	8/31/23	88	O.K.
	2	Mercuric Anilate.	Creosote........	5	D	785 g.	1518 g.	733 g.	48.3	30.8	1.77	....	....	....	0.0935	8/31/23	88	O.K.
	3	Mercuric Anilate.	Creosote........	5	D	763 g.	1229 g.	466 g.	37.9	19.6	1.11	....	....	....	0.0586	8/31/23	88	O.K.
39	1	Mercuric Stearate	1.6% Rubber in C_6H_6	2.0	C	885 g.	1140 g.	255 g.	22.4	10.7	0.613	0.45	0.04	0.049	0.0300	8/31/23	88	attacked not through sheathing
	2	Mercuric Stearate	"	2.0	C	929 g.	1020 g.	91 g.	8.9	3.8	0.218	....	....	....	0.0107	8/31/23	88	"
	3	Mercuric Stearate	"	2.0	C	889 g.	1218 g.	329 g.	27.0	13.8	0.79	....	....	....	0.0387	8/31/23	88	"
40	1	Methylene Blue Copper Tannate	$Cu(Ac)_2$ Sol. (set) (double impregnation)	1	D	1425 g.	1810 g.	385 g.	21.2	16.2	0.93	M.B.1.50 C.T.0.45	....	0.024	0.0224	8/31/23	88	O.K.
	2	"	"	1	D	1648 g.	1860 g.	212 g.	11.4	8.9	0.51	....	....	....	0.0122	8/31/23	88	O.K.
41	1	Rubber Vulcanized	Latex—Sulphur Chloride	30	C	932 g.	1200 g.	268 g.	21.1	11.3	0.648	R. 0.10 S_2Cl_2 0.05	....	0.15	0.0974	8/31/23	88	O.K.
	2	"	"	30	C	900 g.	1253 g.	353 g.	28.2	14.8	0.85	....	....	....	0.1275	8/31/23	88	O.K.
	3	"	"	30	C	900 g.	929 g.	29 g.	3.1	1.2	0.069	....	....	....	0.0104	8/31/23	88	
42	1	Petroleum Fuel Oil	....	....	D	836 g.	1207 g.	371 g.	30.8	15.6	0.895	0.004	....	0.004	0.00358	11/30/23	Still exposed	
	2	"	....	....	D	924 g.	1337 g.	413 g.	30.9	17.3	0.991	....	....	....	0.00396	11/30/23	"	
43	1	Mercury Resinate	Fuel Oil........	3.3	D	780 g.	994 g.	214 g.	21.6	9.0	0.516	0.47	0.004	0.0189	0.00975	11/30/23	Still exposed	
	2	Mercury Resinate	Fuel Oil........	3.3	D	780 g.	967 g.	187 g.	19.3	7.85	0.450	....	....	....	0.00850	11/30/23	"	

TABLE I (*Continued*)

Serial Number	Number	Toxic Used	Vehicle Used	% Weight of Toxic in Vehicle	Method of Impregnation	Weight of Wood	Weight of Wood After Impregnation	Weight of Impregnant	% Weight of Impregnant in Wood	Lbs. of Impregnant per Cu. Ft. of Wood	Lbs. of Impregnant per Sq. Ft.	Cost per Pound of Toxic	Cost per Pound of Vehicle	Total Material Cost of Impregnant per Lb.	Cost of Impregnant per Sq. Ft.	Date Exposed	Days Exposed	Condition of Samples
44	1	Copper Resinate	Fuel Oil	5.0	D	784 g.	953 g.	169 g.	17.8	7.1	0.407	0.06	0.004	0.0069	0.00281	11/30/23	Still exposed	
	2	"	Fuel Oil	5.0	D	987 g.	1164 g.	177 g.	15.2	7.44	0.426				0.00294	11/30/23	"	
45	1	Chlorinated Paraffine	CCl_4	5.0	C	1140 g.	2310 g.	1170 g.	50.6	49.1	2.82	0.05	0.10	0.0975	0.275	11/30/23	Still exposed	
	2	"	CCl_4	5.0	C	1284 g.	2270 g.	986 g.	43.7	41.4	2.37				0.231	11/30/23	"	
46	1	D. A. Oxide	Fuel Oil	1.7	D	1068 g.	1707 g.	639 g.	37.5	26.8	1.54	1.20	0.004	0.0244	0.0376	11/30/23	Still exposed	
	2	D. A. Oxide	Fuel Oil	1.7	D	982 g.	1684 g.	702 g.	41.7	29.5	1.69				0.0413	11/30/23	"	
	3	D. A. Oxide	Fuel Oil	1.7	D	1060 g.	1839 g.	779 g.	42.4	32.7	1.87				0.0456	11/30/23	"	
47	1	D. M.	Chlorinated Paraffine (5% in CCl_4)	5.0	C	984 g.	2213 g.	1229 g.	55.5	51.6	2.96	0.75	0.0975	0.1301	0.386	11/30/23	Still exposed	
	2	D. M.	"	5.0	C	1123 g.	1660 g.	537 g.	32.4	22.5	1.29				0.168	11/30/23	"	
48	1	D. A.	Fuel Oil	1.0	D	1252 g.	1520 g.	268 g.	17.6	11.2	0.641	1.12	0.004	0.0152	0.00975	11/30/23	Still exposed	
	2	D. A.	Fuel Oil	1.0	D	1045 g.	1770 g.	725 g.	41.0	30.2	1.73				0.0263	11/30/23	"	
	3	D. A.	Fuel Oil	1.0	D	1209 g.	1460 g.	251 g.	17.2	10.5	0.601				0.00914	11/30/23	"	
	4	D. A.	Fuel Oil	1.0	D	931 g.	998 g.	67 g.	6.7	2.8	0.160				0.00243	11/30/23	"	
49	1	Phenylarsenious Oxide	CCl_4	1.7	C	1227 g	2462 g.	1235 g.	50.2	51.9	2.970	8.95	0.10	0.1145	0.340	11/30/23	Still exposed	
	2	"	CCl_4	1.7	C	1043 g.	2158 g.	1115 g.	51.7	46.8	2.68				0.307	11/30/23	"	
	3	"	CCl_4	1.7	C	940 g.	1749 g.	809 g.	46.3	33.9	1.94				0.222	11/30/23	"	
50	1	D. A.	Paraffine	1.0	D	991 g.	1348 g.	357 g.	26.5	15.0	0.86	1.12	0.03	0.0409	0.0352	10/12/23	Still exposed	
	2	D. A.	Paraffine	1.0	D	1030 g.	1517 g.	487 g.	32.1	20.4	1.17				0.0478	10/12/23	"	
51	1	Phenylarsenious Oxide	Creosote	1.7	D	1070 g.	1335 g.	265 g.	19.8	11.1	0.636	0.95	0.024	0.0398	0.0253	10/12/23	Still exposed	
	2	"	Creosote	1.7	D	996 g.	1970 g.	974 g.	49.5	40.9	2.34				0.0931	10/12/23	"	
	3	"	Creosote	1.7	D	965 g.	1292 g.	327 g.	25.3	13.7	0.785				0.0312	10/12/23	"	
52	1	D. A.	Creosote	5.0	D	962 g.	1054 g.	92 g.	8.7	3.9	0.224	1.12	0.024	0.0788	0.0177	10/12/23	Still exposed	
	2	D. A.	Creosote	5.0	D	975 g.	1070 g.	95 g.	8.9	4.0	0.229				0.0180	10/12/23	"	
	3	D. A.	Creosote	5.0	D	1302 g.	2137 g.	835 g.	39.2	35 0	2.00				0.158	10/12/23	"	
53	1	Silica	Silica Gel	10.0	C	877 g.	1486 g.	609 g.	41.0	25.6	1.47	0.20		0 02	0 0294	10/12/23	Still exposed	

In the case of crystal violet and methylene blue, the impregnation costs are quite low. These, however, require a double impregnation. Another disadvantage is that the dyes did not penetrate deeply into the wood, although the water penetrated to the core of the pieces and it might be only a question of time before the piece would be severely attacked.

The rubber latex pieces showed some penetration, but a large part of the latex formed a thick film over the surface of the wood and prevented further impregnation. These pieces showed a decided increase in the tensile strength of the wood.

TABLE II. COST OF IMPREGNATION

	Average of 20 Lbs. per Cu. Ft. Material Cost	Labor Cost of Impregnation 6c. per Cu. Ft. per Impregnation	Total Cost
17—Straight creosote	\$0.44	\$0.06	\$0.50
1—Aczol	0.38	0.06	0.44
4—Copper stearate—CC1	0.46	0.06	0.52
5—Double impregnation { 5% $CuSO_4$ / 5% NA_2CO_3	1.60	0.12	1.72
10—Copper hydroxide in 8% ammonia	0.80	0.06	0.86
12—Crystal violet copper tannate (double imp.)	0.21	0.12	0.33
16—Copper studded	0.96	0.10	1.06
19—D. M. in creosote	1.21	0.06	1.27
20—Copper ortho nitro benzoate in creosote	0.71	0.06	0.77
21—Barium phenocresylate (Toxall) in creosote	...	...	...
22—Copper and mercury soaps in pine tar oil	1.02	0.06	1.08
23—Copper benzoate in creosote	1.22	0.06	1.28
24—Mercury benzoate in creosote	1.51	0.06	1.57
25—D. A. oxide in creosote	1.66	0.06	1.72
26—Mercury resinate in creosote	0.93	0.06	0.99
29—Copper resinate in creosote	0.52	0.06	0.58
35—Mercury stearate in creosote	0.91	0.06	0.97
36—Copper hydroxide—4% NH_4OH in 30% rubber latex	0.62*	0.06	0.68
37—Copper stearate in creosote	0.63	0.06	0.69
38—Mercuric anilinate in creosote	1.06	0.06	1.12
40—Methylene Blue—copper tannate	0.48	0.12	0.60
41—Vulcanized rubber latex—sulphur chloride	0.75*	0.12	0.87

*Based on 5 lb. average.

In the test pieces using creosote as a carrier, it is quite possible that immunity is obtained from the presence of the creosote alone. The use of sheathing was intended in these cases to show an improvement over creosote alone. It is fairly well established that the shipworm, after attaining some growth, is able to bore from untreated wood into creosote treated wood, and withstand its toxic properties.* In the above cases, if the shipworm were

*American Wood Preservers' Association—19—"Toxicity of Various Creosote Fractions on Xylotrya."—F. L. Shackell.

killed in crossing over into the treated piece from the sheathing, it would definitely show the toxic effect of the dissolved compound. Due to the trouble with sheathing, no data are as yet available on this point.

After the final inspection, on November 27, 1923, the following test pieces were left on the cable to undergo exposure until attack next spring: 1-1, 5-1, 6-1, 10-1, 18-1, 19-2, 20-2, 21-2, 23-1, 24-2, 25-3, 26-2, 29-2, 35-2, 37-2, 38-2, 40-2, 42-1, 42-2, 43-1, 43-2, 44-1, 44-2, 45-1, 45-2, 46-1, 46-2, 46-3, 47-1, 47-2, 48-1, 48-2, 48-3, 48-4, 49-1, 49-2, 49-3, 50-1, 50-2, 51-1, 51-2, 51-3, 52-1, 52-2, 52-3, 53-1.

All these blocks are sheathed on two sides, and some of this sheathing already contains shipworms, although on the date of the inspection they had not crossed from the sheathing to the block.

V. CONCLUSIONS

1. All of the impregnated pieces used gave better protection than the unimpregnated pieces.

2. The length of exposure was not sufficient to justify too optimistic conclusions, but it is indicated that there are several specific toxics which will give protection through long periods of time.

3. Additional work is necessary before final conclusions can be drawn and the correct estimate of cost of piling protection given.

4. Satisfactory impregnation was secured on the test pieces with practically all the toxics used.

5. It should be possible to duplicate these results readily on large scale apparatus.

6. In the few cases where impregnation was thin or streaky, it was probably due to the fact that the outer surface of impregnated wood was heart wood, which would not be the case with piling.

7. To overcome this objection, it is planned to use eight-foot fence posts in long time service tests.

8. Test pieces impregnated with molten sulphur did not afford protection.

9. Five per cent of specific toxics, such as D.M., D.A., their oxides, phenylarsenious oxide, etc., using creosote as a carrier, seemed to afford definite protection.

10. It is probable that the percentage of specific toxics in these cases can be reduced, possibly to as low as one per cent.

CHAPTER X

HARBOR REPORTS

The information presented in the reports on individual harbors and groups of harbors has been collected from many sources and assembled so that, even at the expense of some repetition of other parts of the report, all available data concerning a given locality might be found in the section of the report devoted to that locality.

The descriptions of the physical characteristics of the harbors are mainly based on "U. S. Coast Pilots" furnished by the Coast and Geodetic Survey, where these were available. Other information has been furnished by representatives of other government departments or by harbor engineers fully conversant with conditions.

The history of attacks by marine borers and the service records of various structures and materials have been secured from the Navy, Army, railroads, harbor boards and others, who were in possession of authentic records.

The records of tests and investigations are compiled from the reports of the biologists who inspected the test blocks and timber, and from other records of the committee.

A draft of these reports was submitted in each case to the District Engineer of the U. S. Engineer Departments, the Superintendent of Lighthouses, and in case of harbors in which Navy Yards or Naval Stations were located, the reports were passed upon by the Public Works Officers. All reports were submitted to the Engineers of Maintenance, Chief Engineers, General Managers or Vice-presidents of the railroads cooperating with the committee and having property in the various harbors, and to the engineers for Harbor Commissioners where such organizations existed, and the suggestions of these engineers were adopted. It is therefore evident that these reports represent not only the results of the studies of this committee but also those of the engineers best qualified to express an opinion in each case.

The maps were made from charts furnished by the Coast and Geodetic Survey, and were prepared in the drafting room of the Western Electric Company, who contributed this service.

In addition to the biologists, Mr. Clapp and Dr. Miller, it is desired to express the gratitude of the Committee to the engineers whose assistance and cooperation made possible the compilation of this information.

MAINE COAST

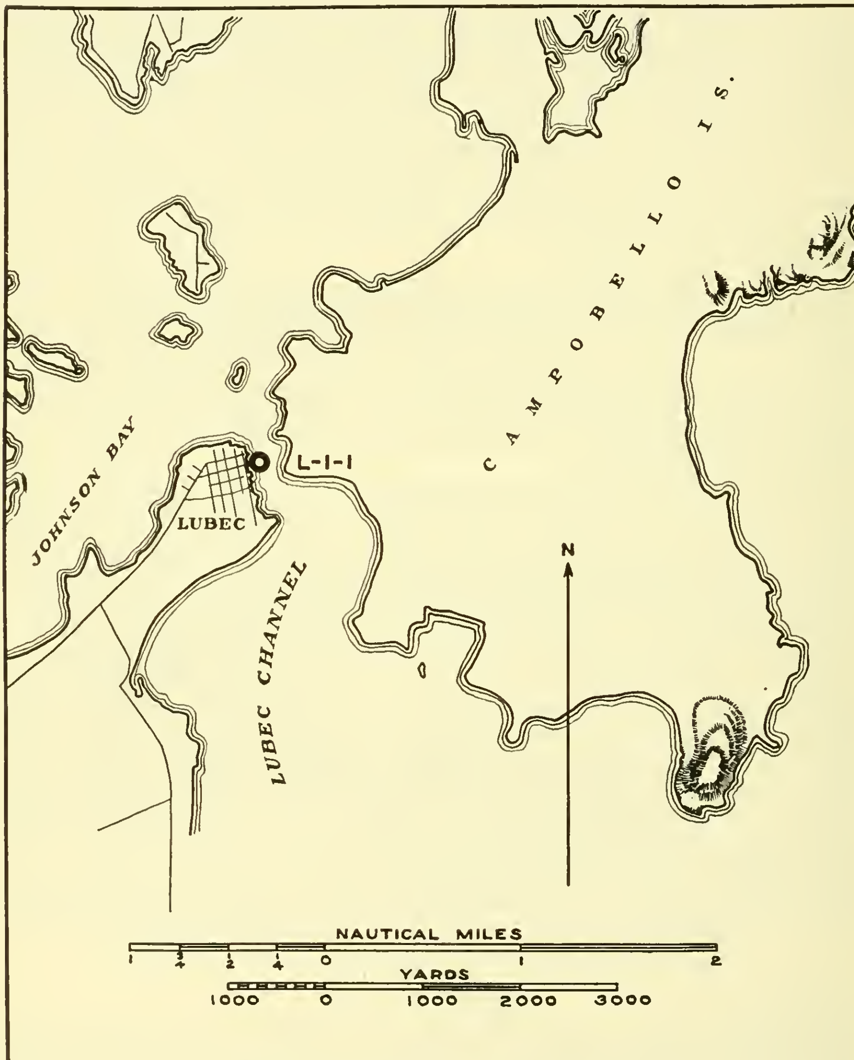
Description

The Maine coast is a region of ledges and boulders, very much broken by numerous bays and rivers, many of which are excellent harbors. Harbors of importance, either commercially or for refuge, are: Little River, Machias Bay, Narraguagas Bay, Winter Harbor, Bar Harbor, Southwest Harbor, Bass Harbor, Castine, Belfast, Camden, Rockport, Rockland, Port Clyde, Boothbay, Bath and Portland.

The prevailing winds are southwesterly during the summer and northerly

during the winter. At all seasons the heaviest gales are generally from northeastward or eastward. The ice formation is generally local, rapidly increasing during calms or light winds when not prevented by tidal currents.

Lubec (Fig. 37), is situated on the western side of Lubec Narrows, a narrow strait connecting it with Mulholland Point. The channel has been



MAP SHOWING LOCATION OF
TEST BOARDS
LUBEC CHANNEL
MAINE 1923

Fig. 37

dredged to a width of from 250 to 400 feet and a depth of 12 feet and has strong tidal currents, the flood attaining, during Spring tides, a velocity of 6 knots and the ebb 8 knots per hour.

Cutler (Fig. 38), a village on the north side of Little River, is the headquarters of many small fishing boats. Little River harbor has 12 to 30 feet of water, is sheltered from all winds and never obstructed by ice.

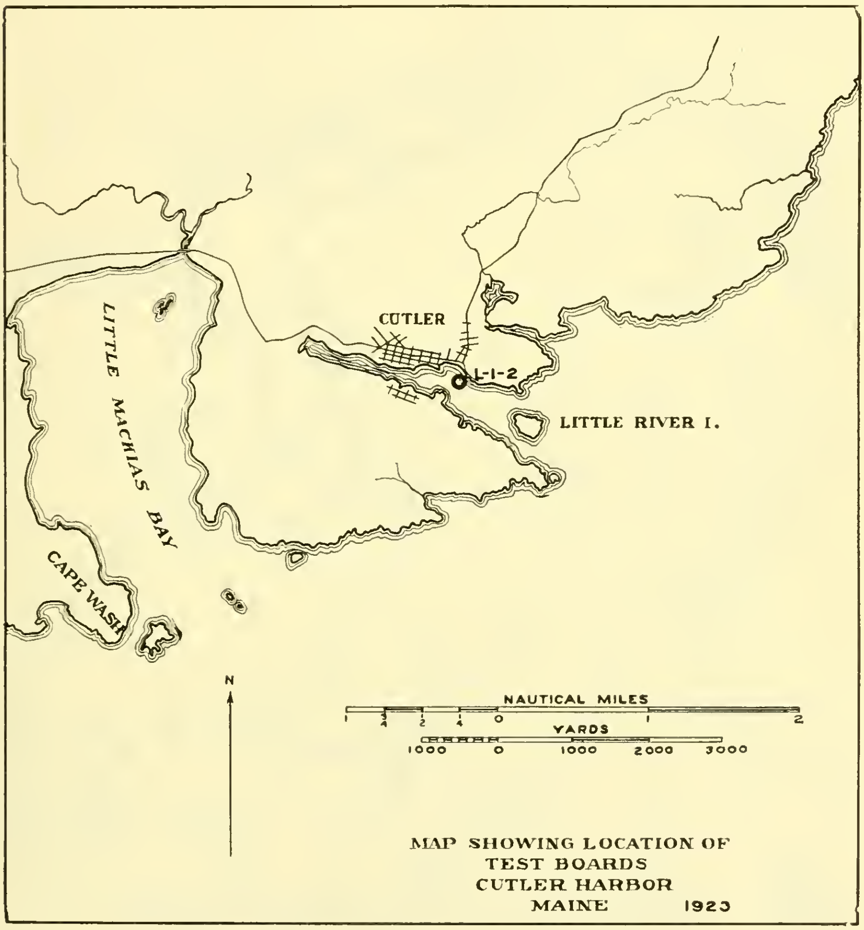


Fig. 38

Crabtree Ledge (Fig. 39), is on the west side of the entrance to Sullivan Harbor, a northwest extension of Frenchman Bay.

Fort Point (Fig. 40), is on the west side at the entrance to Penobscot River. During extreme winters ice forms solidly across the entrance. The average range of tide is 10.3 feet.

Portland Harbor (Fig. 41), is by far the most important harbor on the Maine coast. The following data are taken from "The Port of Portland,

Maine" prepared by the Statistical Division, Board of Engineers for Rivers and Harbors:

General Description.—Portland, Me., is at the westerly end of Casco Bay and is the most northerly and easterly large port on the Atlantic coast of the United States. The harbor is 3⅓ miles from the open ocean.

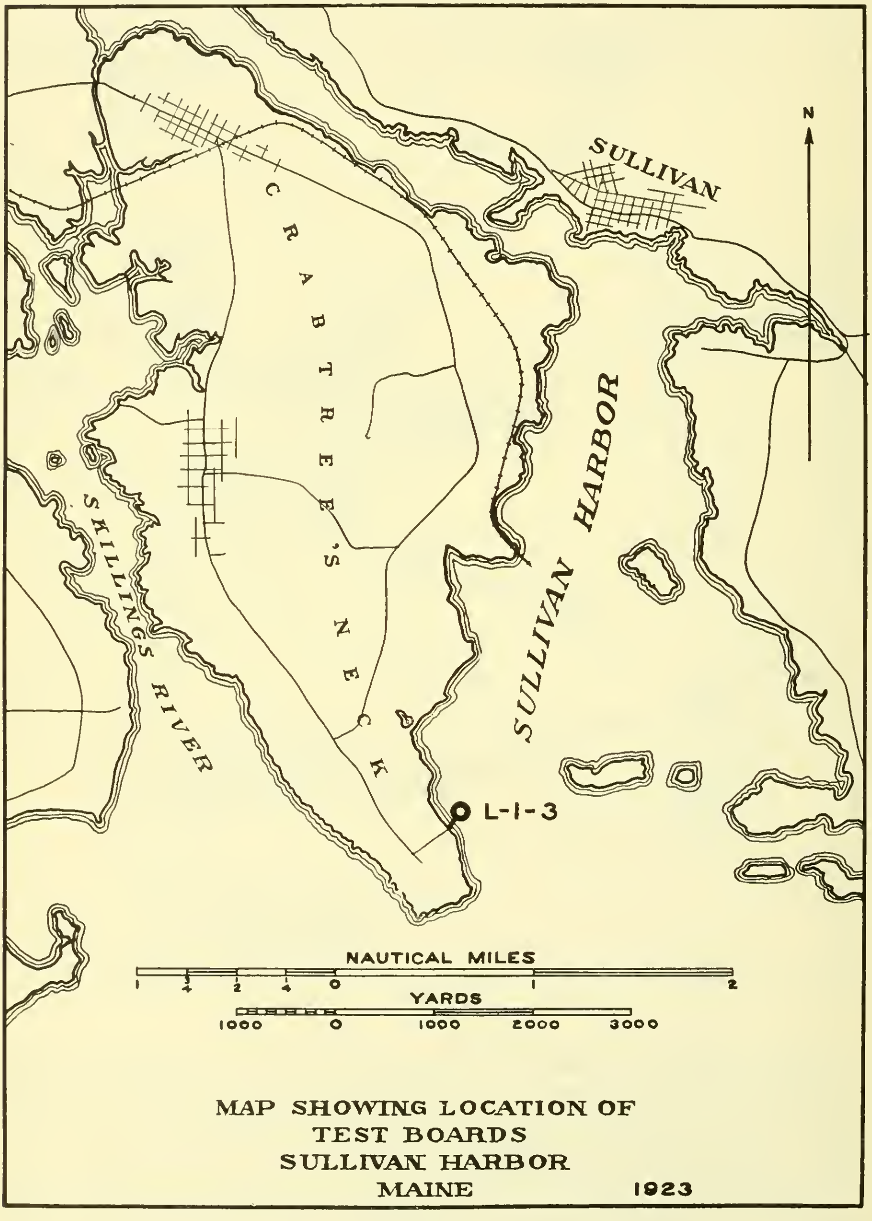


Fig. 39

The harbor, considered as a whole, is made up of three parts:

(a) The main or inner harbor, known as Front Harbor, lying south and east of the peninsula, and having a water front of about 2½ miles;

(b) Fore River, also on the southerly side of the peninsula, extending westerly from the main harbor (from which it is separated by Portland Bridge), for about 1⅓ miles;

(c) Back Cove, which lies on the northerly side of the peninsula, nearly landlocked, approximately circular in form, is about 1 mile in diameter, having a narrow bottlenecked entrance. It has a water front of about 1¾ miles.

The total water frontage of the harbor, inclusive of South Portland, is about 8½ miles.

The outer harbor of Portland, which is used as a harbor of refuge, is situated behind the islands of Casco Bay. The main ship channel to Portland Harbor is the deep-water entrance between Cushing Island on the east and the main shore at Portland Head on the west. There are several other

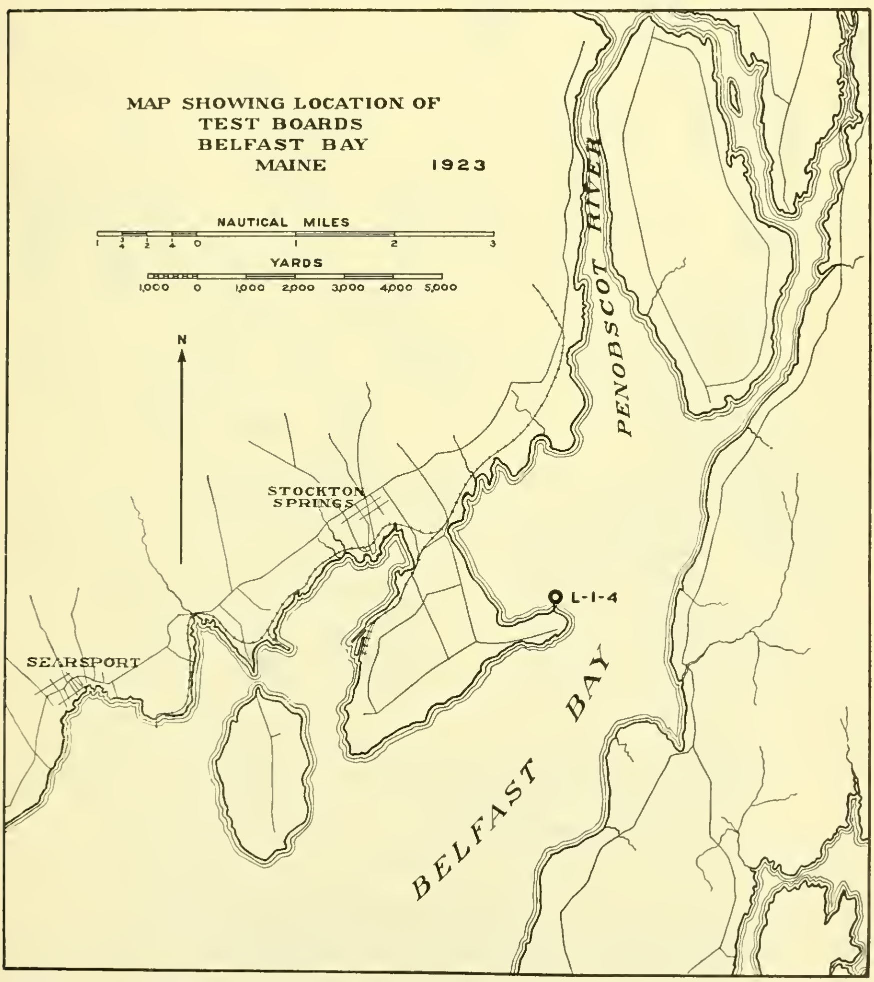


FIG. 40

entrances between the islands used by local vessels or those towing from Portland to different points in Casco Bay and its estuaries.

TIDES.—The mean range of tide is 8.9 feet, and the spring range 10.2 feet. In 1909 there was a tide of 13.3 feet and tides of 11 feet are not uncommon. The effect of strong winds, in combination with the regular tidal action, may at times cause the water to fall below the plane of reference of the chart as much as 4.5 feet.

Tidal currents exist principally near the bridges, but their velocity never exceeds 2 miles per hour. At Portland Light Vessel the tidal current is weak, being on an average less than ¼ knot; during October, November and December there is a southerly set of about ½ knot.

Ice seldom obstructs navigation and when it does it is only for a limited period. The channel to the wharves is kept open by steamers and tugs.

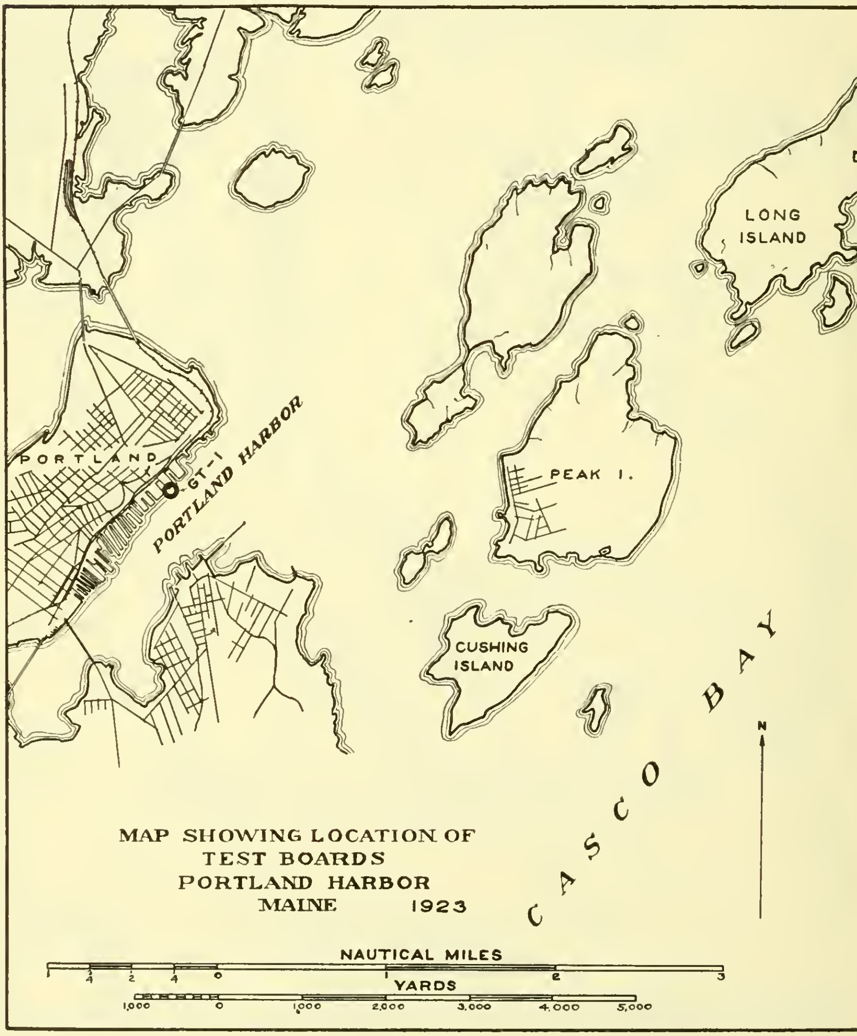


FIG. 41

Marine Borers

Past History—Damage done by *Limnoria* has been reported to have occurred to the Bear Island Lighthouse Depot Wharf, Northeast Harbor, Maine, and the Little Island Lighthouse Depot Wharf.

In May, 1923, a wharf at Lubec collapsed. The cause was said to be the jamming of the ice against the building and lifting it from its foundation, but an inspection of the pile supports showed that many of them were badly eaten by *Limnoria.*

The outer end of one of the Grand Trunk Railway wharves at Portland failed in 1922 on account of the destruction of the piles by *Limnoria.* (Fig. 42).

The shipworm is also known to be present at Portland, but no considerable damage has been reported.

Committee Investigations—Test boards were installed as shown in the following table:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Lubec—Boat Landing	L-1-1	Lighthouse Service	May 5, 1923	0.7	6.2
Cutler—Little River	L-1-2	Lighthouse Service	May 1, 1923	1.0	9.0
Crabtree Ledge—Light	L-1-3	Lighthouse Service	May 1, 1923	1.0	8.5
Fort Point—Wharf	L-1-4	Lighthouse Service	April 28, 1923	1.0	8.0
Portland—Cross Shed No. 1	GT-1	Grand Trunk Railway	May 30, 1923	10.0	18.0
Scarboro—Bridge No. 117, seven miles north of Pine Pt	BM-12	Boston & Maine R.R.	July 21, 1922	*0.0	1.0
Old Orchard—Bridge No. 42	BM-11	Boston & Maine R.R.	July 11, 1922	*Board out low tide.	of water at
York Harbor—Bridge No. 236 one-half mile east of Seabury (Fig. 44)	BM-9	Boston & Maine R.R.	July 20, 1922	*1.0 †3.0	14.0 11.0
Kennebunkport (Fig 43)	BM-10	Boston & Maine R.R.	July 10, 1922	0.0	5.0

*Placed in horizontal position.
†Changed to vertical position December 15, 1922.

L-1-1—The first *Limnoria* was found on the second block, removed June 16, and from this time to October a number of specimens of *Limnoria* varying from 100 down to 20 were found. While not in great numbers, the burrows of these animals were unusually large and deep. The last test block inspected was removed October 16, 1923.

L-1-2—A few specimens of *Limnoria* only were found on each block removed and some Bryozoa appeared on the blocks removed after August 1. The last test block inspected was removed October 16, 1923.

L-1-3—A few specimens of *Limnoria* were found on all blocks removed after July 1, and most blocks after this time showed traces of *Balanus* and Bryozoa (*Lepralia*), indicating the possibility of shipworm attack. The last test block inspected was removed October 16, 1923.

L-1-4—*Limnoria* did not appear until August 1, but both *Balanus* and Bryozoa were present on a number of blocks. The last test block inspected was removed October 16, 1923.

GT-1—*Limnoria* appeared on the first block and by October the attack was fairly heavy, amounting to destruction to a depth exceeding ⅛-inch. The last test block inspected was removed October 31, 1923.

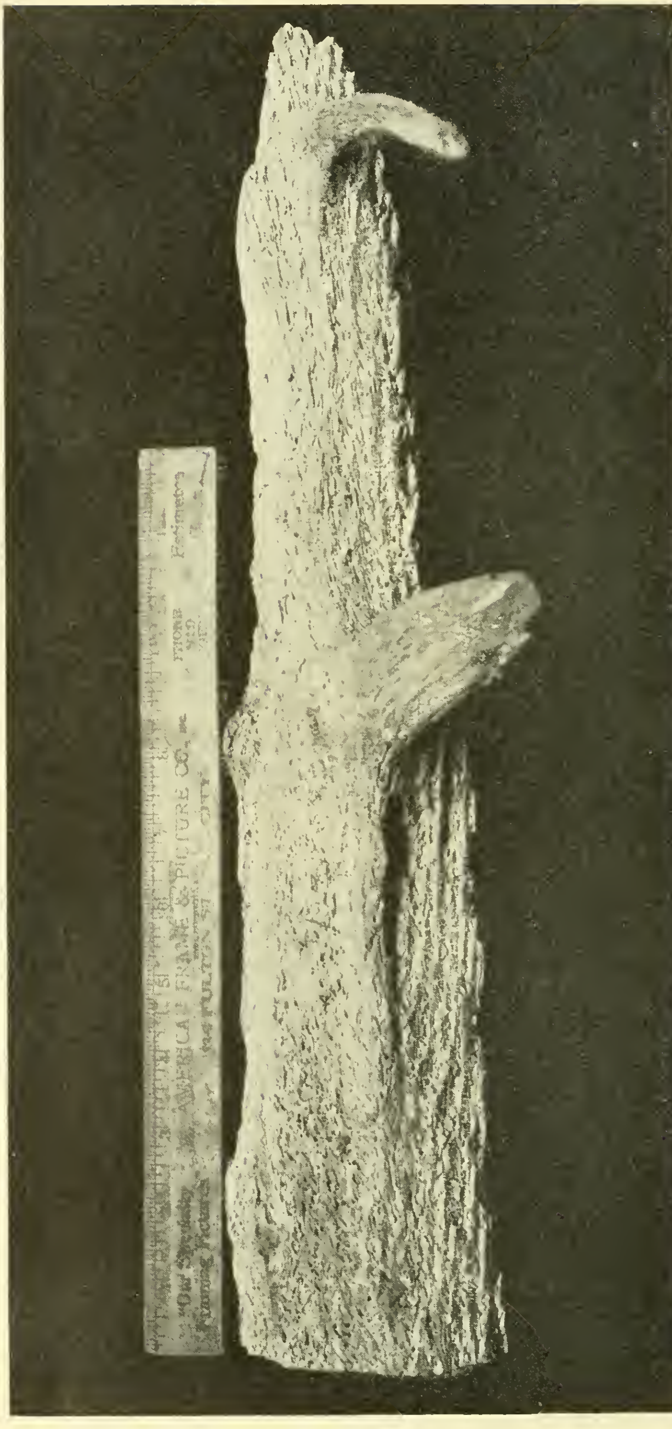


FIG. 42—SECTION OF PILE DRIVEN IN GRAND TRUNK RY. PIER AT PORTLAND, MAINE, SHOWING *Limnoria* ATTACK. PIER DESTROYED BY BORERS

BM-12—No borers were found. Associated organisms were *Balanus*, *Mytilus* and some Algae. The last test block inspected was removed July 27, 1923.

BM-11—No borers and no associated organisms except some Algae were found. The last test block inspected was removed July 26, 1923.

BM-9—A few scattered specimens of *Limnoria* appeared on most of the blocks. One specimen of *Teredo* (*Psiloteredo*) *dilatata* was found in the block removed May 1, 1923. Other organisms found were *Mytilus*, sometimes in large numbers, *Anomia*, *Saxicava*, *Zirphaea crispata* and a few specimens of *Balanus*. The last test block inspected was removed July 24, 1923.

BM-10—No borers and a few specimens of *Mytilus* and *Balanus* were found. The last test block inspected was removed July 27, 1923.

Methods of Protection

The piles at the Bear Island Depot Wharf, of the Lighthouse Service, built in 1890-1892, were brush-coated with carbolineum and are reported to have given satisfactory service.

Piles treated with 16 lb. of creosote per cubic foot were used in the State Pier at Portland constructed in 1922, but before this time, few piles along the Maine coast were protected.

Several piles protected by wrapping with ½-inch copper strips were placed for test under shed No. 1 of the Grand Trunk Ry. at Portland in 1923.

Substitutes for Timber

Concrete—Reports have been received from the Corps of Engineers, U. S. A., on four structures located at Portland, the substance of which is as follows:

SEAWALL AT FORT LYON.—This wall, about 450 feet long, is built on a ledge, and at its lowest point is ½-ft. above M.L.W. This wall was built in place in 1905 of 1:3:6 concrete. The materials were crushed granite, salt water beach sand, Alpha Portland cement, and fresh water.

In 1916 the wall was reported to be in excellent condition, except for a length of about 35 feet where it is exposed to severe wave action during storms and some undercutting was evident. The balance of the wall, which is protected against wave action to some extent by outlying ledges, showed no signs of disintegration.

In 1922 it was reported that about 75 feet of this wall which was repaired in 1917 showed some deterioration, but not sufficient to require immediate repair.

REVETMENT AT FORT LYON.—This revetment is a slope pavement of concrete, about 6 inches thick, over a pavement of partly disintegrated native rock. It is about 140 feet long, and covers the lower slope of a sand epaulement. Only a few feet of it are covered by water at high tide. It was constructed in 1908 of 1:2½:5 concrete, poured in place, and composed of materials similar to those of the Fort Lyon seawall.

In 1916 it was reported that there was no disintegration. It is now reported (1922) that this revetment is in first class condition, except in a few places at the lower end, where the concrete paving has been broken off.

WHARF AT FORT WILLIAMS.—The walls from shore to low water line were

built of 1:2½:5 concrete, poured in place; below low water, they were built of precast blocks with same mixture, cured 30 days before being placed. The concrete was composed of Dexter cement, clean pit sand, crushed native rock, and fresh water. The wharf was built in 1908. It extends out from shore to a depth of about 13 feet at mean low water and is exposed to the

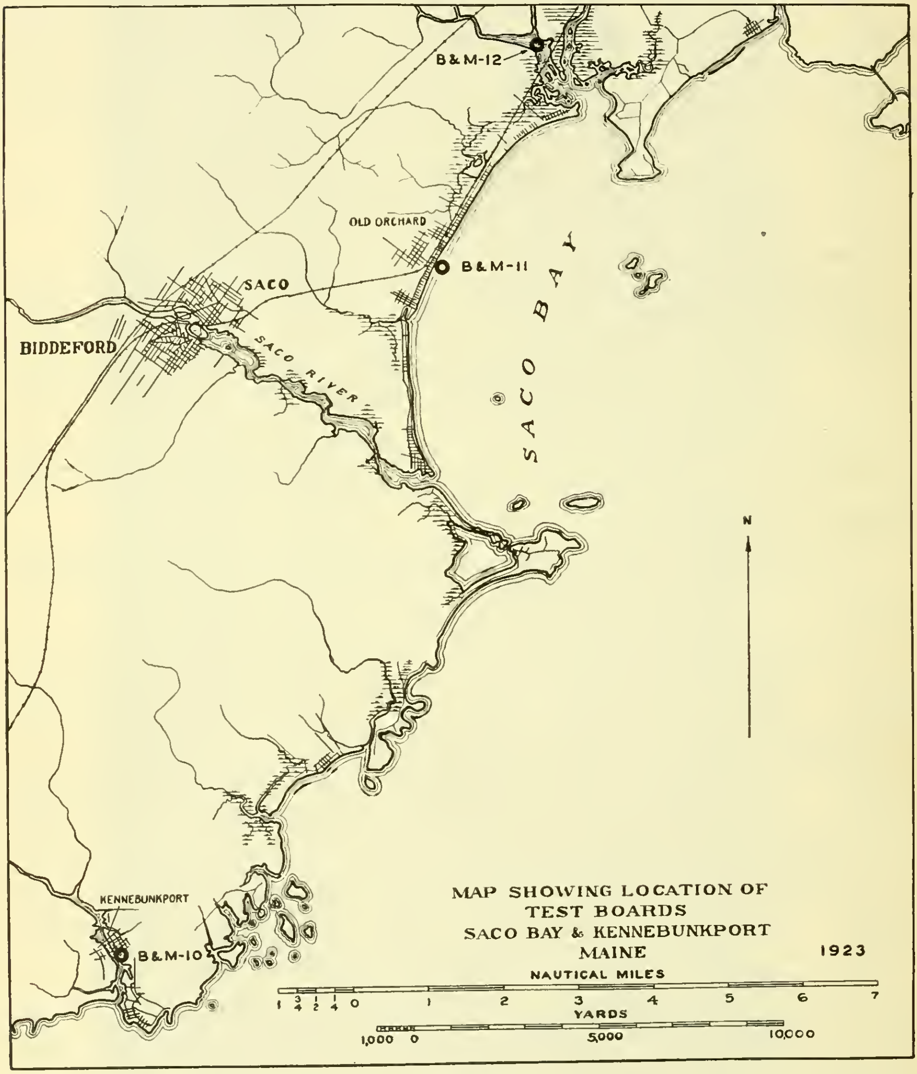


FIG. 43

full force of easterly and southeasterly storms. Rocks and ice are hurled against it and are often left upon the deck.

In 1910 cavities began to appear between high and low water, principally on the most exposed or easterly face, and on that part which had been built of mass concrete. This disintegration continued until 1912, when it had

extended to include the blocks on the easterly side. At this time the worst section formed a belt on the easterly side at and below high water, with some of the cavities having a maximum depth of about 6 inches. By 1914 the concrete surfaces on all sides as well as on the deck showed considerable disintegration, the faces of the blocks being as bad as the mass concrete.

In 1918 repairs were made by removing disintegrated concrete on the front and sides of about 3000 square feet of surface, and placing a new facing, requiring about 100 cubic yards of concrete.

In 1921 practically the same work of repair had to be done. A considerable amount of the last patching was either distintegrated or so loosened that it had to be cut out and replaced by new concrete.

Seawall at Fort McKinley.—This wall is about 250 feet long and was built in 1914 of 1:2:4 concrete. The materials were like those of the Fort Lyon seawall, except that the concrete was cyclopean, using native rock of considerable size.

In 1916 it is reported that there was no sign of disintegration but in 1922 a very slight deterioration was reported. There are also a few places where the rock on which the wall was built is decomposed, leaving openings under it.

Conclusions

Limnoria is present in practically all harbors on the Maine coast and the timber supports of important structures, especially those having permanent decks or carrying buildings, should be protected. The service records of concrete structures which could be obtained do not show that these structures have been very satisfactory in these waters and long life should not be expected unless the surface is protected from mechanical and chemical attack.

PORTSMOUTH, N. H. TO PROVINCETOWN, MASS.*

Description

From Portsmouth south to Cape Ann the coast line is low and generally a sandy beach, with the exception of the northern shore of Cape Ann, which is high and rocky. Between Cape Ann and Plymouth the coast is rock, boulders and sunken ledges lying near the shore with deep channels between. The shores of Cape Cod Bay are generally sandy with extensive sand shoals extending well out from shore in many places. Throughout this entire section of the coast line the prevailing winds are southwesterly during the summer and northerly during the winter. In severe winters some of the harbors are usually kept open by steamers and tugs.

Portsmouth Harbor (Fig. 44), lies 37 miles southwestward of Cape Elizabeth and about 25 miles northward from Cape Ann, and is formed by the mouth of the Piscataqua River. During severe winters the water temperature reaches 28½ degrees Fahr., the maximum summer temperature ranging between 60 and 64 degrees Fahr. There is a variation of from 3 to 4 degrees due to the tide, the temperature rising in winter and falling in summer with the incoming tide. The mean tidal range is approximately 8 feet; during spring tides, 9.3 feet. Tidal currents are of high velocity, reaching at times 6 knots, due to the large tidal area of Great Bay up the river. Very little fresh water in comparison with the tidal volume reaches

*See separate report for Boston, Mass.

the harbor. The salinity of the harbor water is therefore practically that of the ocean. The water is very clear containing little sewage or manufacturing wastes and with the exception of a portion of the U. S. Navy Yard shore line, practically no oil pollution. At the latter point there is a thick coating of oil deposit on the quay walls and piles from near the high water mark to 3 or 4 feet below.

Newburyport Harbor (Fig. 45), is located on the Merrimac River,

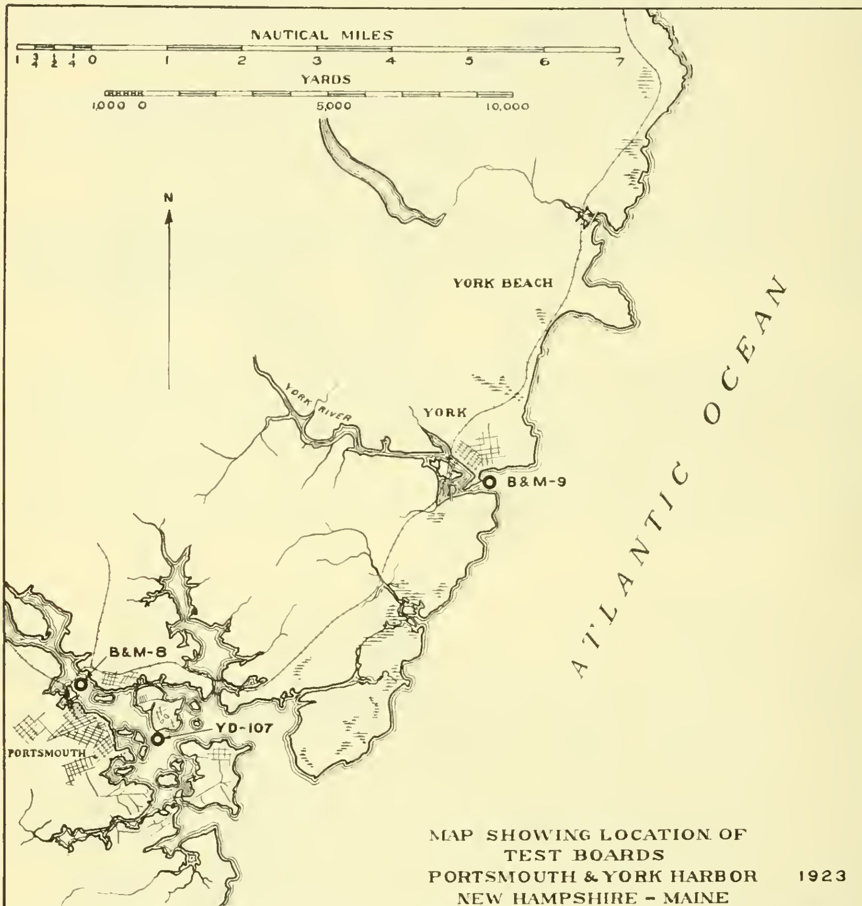


Fig. 44

about 3 miles from its mouth. There is a shifting bar at the entrance with 10 to 13 feet of water over it, and a channel depth to the harbor which will accommodate vessels of 17 feet draught at high water.

Beverly Harbor (Fig. 46), lies north of Salem Neck at the west end of Salem outer harbor and is formed by the confluence of Danvers River, Beverly Creek and North River. The channel has been dredged to a depth of 18 feet and 200 to 300 feet width.

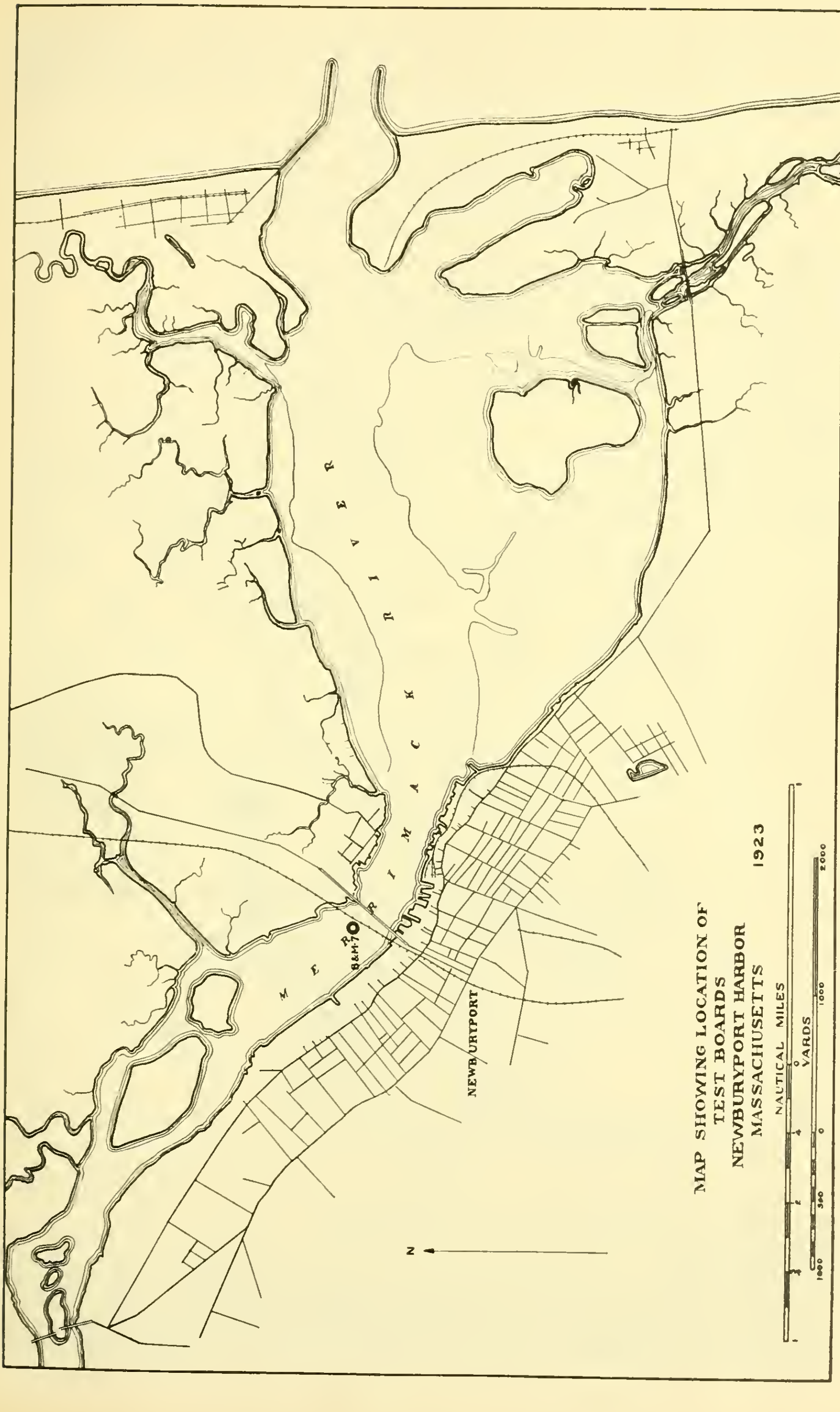

MAP SHOWING LOCATION OF
TEST BOARDS
NEWBURYPORT HARBOR
MASSACHUSETTS
1923
NAUTICAL MILES
YARDS
MERRIMACK RIVER
NEWBURYPORT
B&M 7
N

FIG. 45

Provincetown Harbor (Fig. 48), is formed by a turn in the northern end of the hook of Cape Cod and has a diameter of about 2 miles. The depth at the entrance and in the harbor is ample for vessels of deep draught. The principal wharves are the steamboat and railroad wharf and

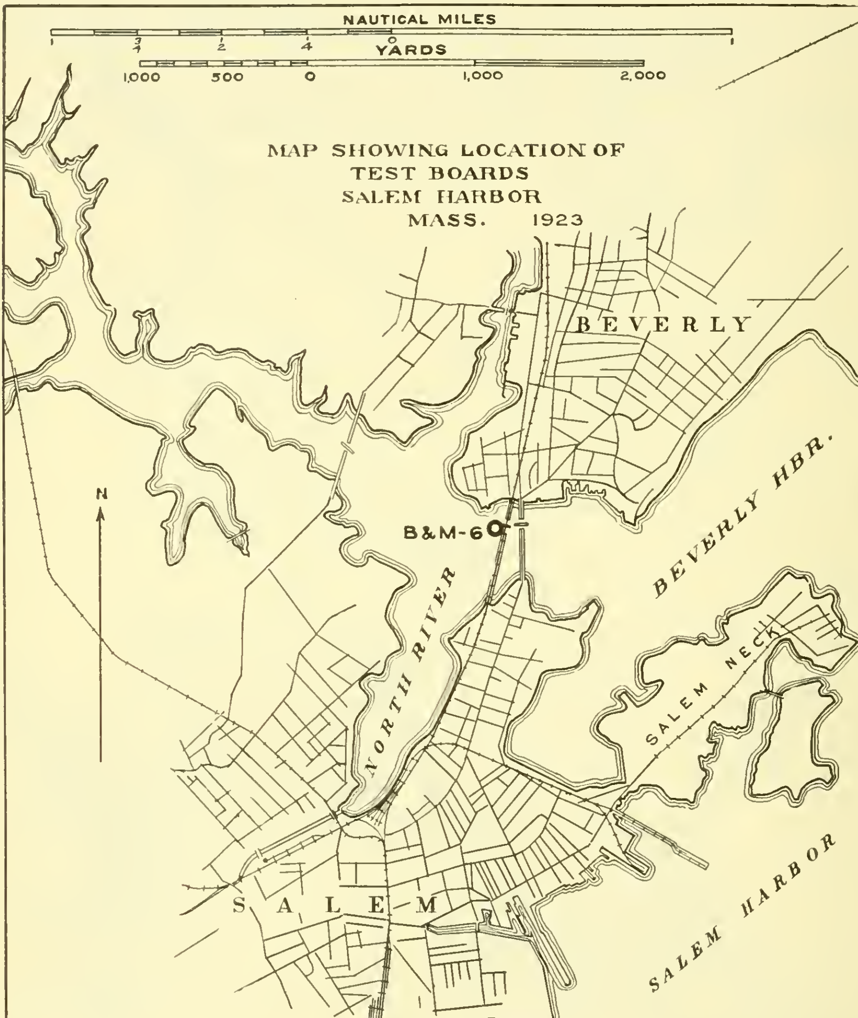


Fig. 46

a fish and cold storage wharf. At mean low water the depths at the outer ends of these two are 8 and 7 feet respectively.

Marine Borers

Past History—*Limnoria* is present generally throughout this territory. The wooden stocks of some old anchors taken from the bottom of the Piscataqua River about 17 years ago were found to be practically destroyed

by *Limnoria.* The depth at this point was 40 feet. While repairing the old bridge at the Navy Yard at Portsmouth in 1912, many of the piles which had been in place for 25 to 30 years were found to have been eaten off at the mud line and a recent inspection shows that some of those which

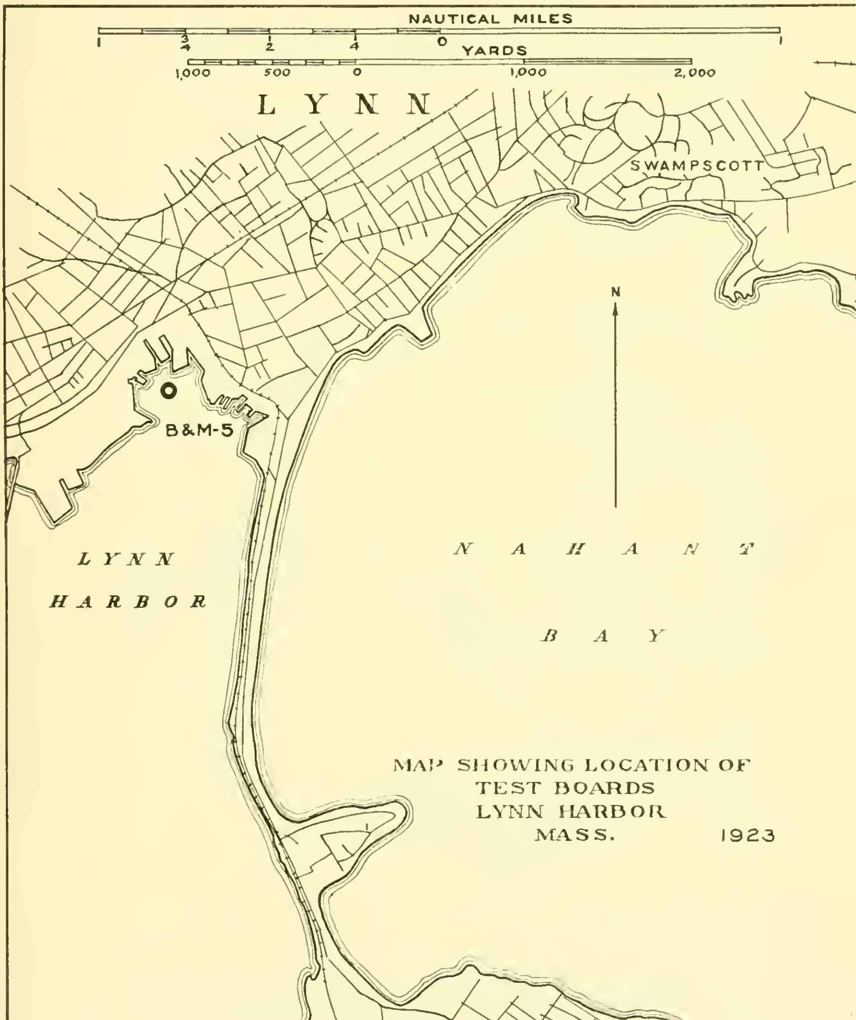


Fig. 47

were allowed to remain are completely eaten off up to about extreme low water, whereas replacement piles which were driven about 17 years ago are still in good condition. Some damage by shipworms has also been reported.

Committee Investigations—Test boards were installed as shown in the following table:

Location	Symbol	Date Installed	Installed By	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Portsmouth—B. & M. Bridge No. 70	BM-8	July 7, 1922	B. & M. R. R.	*0.0 †3.0	22.0 19.0
Portsmouth—Henderson's Point	YD-107	Jan. 2, 1923	Navy	27.0	8.0
Newburyport—B. & M. Bridge No. 50	BM-7	July 6, 1922	B. & M. R. R.	*0.0 †2.0	17.5 14.5
Beverly—B. & M. Bridge No. 32	BM-6	July 6, 1922	B. & M. R. R.	0.0 †2.0	14.0 12.0
Revere—2.1 miles north of B. & M. Bridge No. 14 (Fig. 47)	BM-5	July 22, 1922	B. & M. R. R.	*0.0	3.0
Provincetown—R. R. Wharf	NH-2	June 2, 1922	N.Y.N.H. & H.R.R.	1.0	4.0

*Board in horizontal position.

†Boards changed to vertical position on the following dates: Jan. 2, Portsmouth; Jan. 11, Newburyport and Beverly.

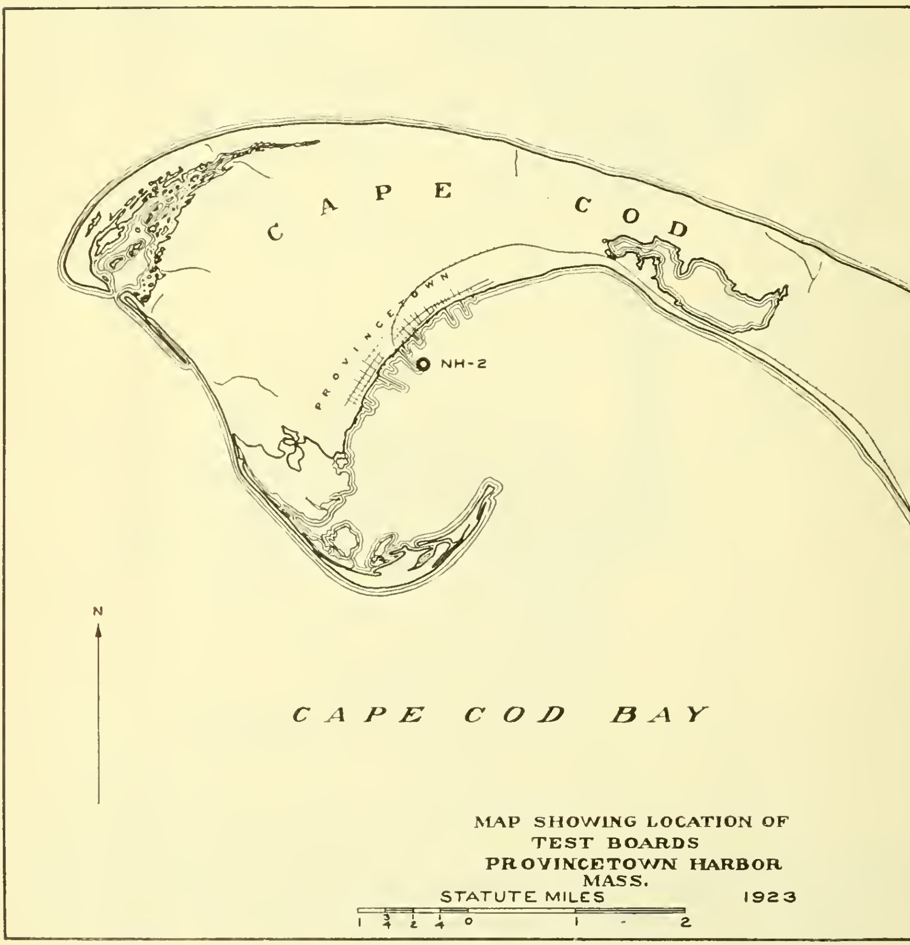


Fig. 48

The results of the inspection of test blocks from these boards were as follows:

BM-8—*Limnoria* first appeared July 7, 1922, and continued to appear on many of the blocks though few in number. The associated organisms were *Anomia, Mytilus, Balanus and* Bryozoa (*Lepralia*), the two latter indicating the possibility of shipworm attack appearing in 1923 but not in 1922. The last test block inspected was removed July 20, 1923.

YD-107—No life whatever appeared until June 18, when a few *Balanus* and Algae were found. Later a few specimens of *Saxicava* and *Mytilus* appeared but no borers were found in the blocks. The last test block inspected was removed September 20, 1923.

Specimens of timber from several of the structures at the Navy Yard showed considerable *Limnoria* action and some *Teredo* attack. The largest specimen of *Teredo navalis* found on the Atlantic Coast was in one of these timbers.

BM-7—Only one test block of the 25 examined showed any life and this one had two specimens of *Limnoria,* a few *Mytilus, Saxicava* and a little Algae. The last block inspected was removed July 25, 1923.

BM-6—*Limnoria* was found on many of the blocks but seldom exceeding 30 in number. Associated organisms were *Anomia, Mytilus, Pecten, Ostracoda,* Foraminifera and Bryozoa (*Lepralia*). The last block inspected was removed July 26, 1923.

BM-5—A very few specimens of *Limnoria* appeared on a few blocks. Associated organisms were *Balanus* with a little Algae. The last block inspected was removed July 24, 1923.

NH-2—The *Limnoria* attack was heavy and some specimens of *Sphaeroma destructor* appeared. *Teredo navalis* numbering from two or three to 20 was found in many but not all blocks. The largest animal measured was about 5 inches in length. One specimen of *Teredo dilatata* about 10 inches in length was also found.

Associated organisms were *Mytilus,* Bryozoa, Foraminifera, *Pecten,* Algae and a few specimens of *Limacina balea.*

In addition to the test blocks several specimens of piles, both oak and chestnut, were examined. They were practically destroyed after a service of from 10 to 18 years.

Methods of Protection

Very few structures have been protected against borer attack though the practice of driving piles with the bark in place has been quite general. There are few definite records as to the life of structures in any of these harbors but it is thought that unprotected pine will last from 15 to 20 years and oak slightly more at Portsmouth and perhaps half this length of time at Provincetown.

Substitutes for Timber

Concrete—The only concrete structure reported by the Navy is the arched quay wall under the coaling plant of the U. S. Navy Yard at Portsmouth, built in 1902 and 1903. It is 233 feet long and consists of 6 concrete arches resting on 7 piers, which in turn rest on ledge rock. The facing edge of the intrados and the coping is granite. The stone fill back of

the wall arches is held by a timber crib up to about the low water line with a concrete curtain wall above this level.

It is exposed to salt water and spray and to moderate wave action and abrasions. The climatic influences and atmospheric conditions are severe.

The piers (9 ft. by 23 ft. at the top) were built by depositing concrete under salt water from a bottom dump bucket in a wooden form from which the water was not excluded. The form having been placed on the ledge was first made tight around the lower edge by concrete in bags.

Atlas and Phoenix brands of Portland cement, Plum Island sand, and broken trap rock from the Navy Yard were used in the proportions of 1:2:4 below, and 1:3:6 above high water, the gauging water partly fresh and partly salt, the consistency "mushy." There are steel I-beams across the arches and short steel I-beams where the columns of the coaling plant rest. There were tie rods to take the thrust of the arch until the adjacent quay wall should be built.

The piers were examined by a diver in 1920 and were reported to be in generally good condition. The present condition of the arches is poor to fair. There are a number of eroded areas on the intrados, the worst being about 15 inches deep and at the rear of the arches, immediately above the piers, there are three badly eroded places. The curtain wall is badly eroded, in one place clear through. The face has a number of eroded places, in some cases as much as 12 inches deep, but not of great surface area.

A concrete monolith at Sandy Bay Breakwater, Cape Ann, is reported by the Army as follows:

> A 90-ton concrete monolith in the Sandy Bay breakwater, with its base about 4 feet above mean high water, and its top 4½ feet higher, was built in place in 1910. The concrete was made in the proportion of 1:2½:5 of Atlas cement, salt water sand, crushed granite, and sea water.
>
> The exposure to wave action is severe.
>
> Pitting on the surfaces of the concrete was noticeable within a year after it was poured, and up to 1916, the year of the last report, the deterioration had been progressive.

Conclusions

Except at Portsmouth and Provincetown the tests do not show attacks of much importance and at Portsmouth they are not heavy. It would seem that protection for wooden piles used for important structure in either of these harbors would be an economy. It does not seem so necessary in the small harbors in which the tests were made except for structures where long life is important.

Concrete structures on which reports are quoted, or on which the construction data are incomplete and are therefore not included, do not seem to have generally given satisfactory service in salt water on account of the combined attack of waves, sulphates and ice.

BOSTON HARBOR

Description of Harbor

The following description of Boston Harbor, (Fig. 49), is taken from a report, "The Port of Boston, Mass.," prepared by the Board of Engineers for Rivers and Harbors, War Department, in coöperation with the Bureau of Research, U. S. Shipping Board:

> General Description.—Boston is situated on Massachusetts Bay, and is one of the most important ports of the United States, considered both from

FIG. 49


MAP SHOWING LOCATION OF
TEST BOARDS
BOSTON HARBOR
MASS. 1923
NAUTICAL MILES
YARDS
1,000 500 0 1,000 2,000
N
B&M-4
CHELSEA
B&A-2
B&M-3
B&M-1
CHARLESTOWN
YD-105
EAST BOSTON
B&A-1
B&M-2
NH-1
ASR-1
BOSTON
A-27
SOUTH BOSTON
PRESIDENT ROADS
OLD HARBOR
A-28
NANTASKET ROADS
DORCHESTER BAY
YD-106
A-29
LITTLE HOG I.
HINGHAM BAY
QUINCY BAY

the wall arch
a concrete cu
It is expos
abrasions. T
The piers
under salt wa
the water w
was first mad
Atlas and
broken trap
1:2:4 below,
and partly sa
the arches an
rest. There
quay wall sho
The piers
generally goo
fair. There
about 15 inch
piers, there a
in one place
some cases as
A concrete
the Army as

> A 90-t
> about 4
> in place
> Atlas ce
> The ex
> Pitting
> it was p
> had beer

Conclusions

Except at
much import
that protectio
these harbors
small harbors
long life is in
Concrete st
struction data
have generall
combined atta

Description o

The followi
report, "The
for Rivers an
of Research,

> GENER
> is one of

the standpoint of its facilities and the extent and value of its commerce. The harbor includes all the tidewater lying within a line from Point Allerton to Point Shirley, comprising an area of about 47 square miles, exclusive of the islands. The entrance between these two points is about 4¾ miles wide and the distance from the Point Allerton-Point Shirley line to the Charlestown Navy Yard, via the 35-foot channel, is about 7½ miles.

The City of Boston includes within its limits East Boston, Charlestown, South Boston, Roxbury, Dorchester and Neponset. East Boston is on the northeastern side of the harbor, and is separated from Boston proper and Charlestown by the main ship channel, and from Chelsea by Chelsea Creek. South Boston fronts on the bay and the lower part of the main ship channel, and is separated from Boston by the Fort Point Channel. Charlestown fronts on the main ship channel at its upper end and on Mystic River and Charles River, and is separated from Boston proper by the latter stream.

The Outer Harbor.—Boston Harbor and approaches have a very broken rocky bottom. President Roads is a deep water anchorage area between Deer Island and Long Island at the entrance to the outer harbor, and is the common point to which all important channels of the outer harbor converge.

There are three main channels of entrance from the sea to President Roads, with depths respectively of 35 feet, 30 feet and 27 feet, and widths of 1,500 feet, 1,200 feet and 1,000 feet. There are also five minor channels with depths of from 8 feet to 18 feet.

The Inner Harbor.—The main ship channel with a depth of 35 feet and a width of 1,200 feet extends from President Roads to the upper end of the Navy Yard at Charlestown and with a somewhat less depth to the bridges across the Charles and Mystic Rivers and Chelsea Creek.

Charles River, the approach to Cambridge and Watertown, has a depth of 21 feet between the bridge and dam, a distance of about ½ mile. Above the dam the water is practically fresh.

The Mystic River, leading to Medford and Malden, has a depth of 30 feet and a channel width part 500 and part 600 feet to a point about ⅜ mile below the second bridge; above this point the depth is about 6 feet.

Chelsea Creek from the lower bridge to the Chelsea Street Bridge has a depth of 25 feet and a width of 150 feet.

There are a number of short channels tributary to the Mystic River and Chelsea Creek which have been dredged to depths of from 23 feet to 28 feet with varying widths.

Tides.—The mean range of tides is 9 feet at Boston Lighthouse and 9.6 feet at Charlestown Navy Yard, in Chelsea Creek, and in Fort Point Channel. The extreme range is about 4 feet greater.

Tidal Currents.—For some distance northwestward of Cape Cod the tidal currents have a slight set southward into Cape Cod Bay on the flood and eastward out of the bay on the ebb. Along the northern shore of Massachusetts Bay the flood sets in a general westerly or northwesterly direction and the ebb in a southerly or southeasterly direction. The velocity of the currents is influenced greatly by the force and direction of the wind. Off the entrance to Boston Harbor the flood sets westward and the ebb eastward, increasing slightly in velocity as the entrance is approached.

The tidal current at Boston Light Vessel is small, averaging about one-fourth knot at the time of strength. Its greatest velocity observed during three months in autumn was less than 1 knot.

The maximum velocity of the tidal currents in the various harbor channels varies from ½ to 2 knots except in the Nantasket Gut, where it reaches 5 knots.

The mean annual precipitation is 43.38 in., distributed evenly throughout the year. Prevailing winds are southwesterly during the summer and northerly during the winter—the heaviest gales being always from east or north eastward. In severe winters the greatest part of the harbor is frozen over, the channels being kept open by towboats and steamers. All sewage is emptied into the ocean at ebb tide, none entering the harbor. The temperature of the atmosphere ranges between —14° and 104° Fahrenheit, the annual mean being 49.4°.

Marine Borers

Past History—Shipworms have been found in waterfront structures of Boston Harbor to a limited extent. The probability of serious damage in a short period of time is thought to be remote. *Limnoria* is active at times and has been known to so weaken structures as to require a considerable amount of replacement work, as was the case with Pier 5, Charlestown Navy Yard, where in 1913 it was found that over 100 piles had been eaten away at the mud line. All of the piles attacked were spruce—pine and oak remaining uninjured.

Committee Investigation—Standard test boards were installed as follows:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
South Boston Coal Dock	NH-1	N.Y.N.H. & H.R.R.	June 1, 1922	0.0	12.0
Drawbridge No. 2—Millers River	BM-1	B. & M. R. R.	July 1, 1922	0.3	†2.0
Wharf No. 46	BM-2	B. & M. R. R.	July 1, 1922	0.3	*5.4
Drawbridge No. 6—Charles River	BM-3	B. & M. R. R.	July 1, 1922	0.3	†13.0
Drawbridge No. 7	BM-4	B. & M. R. R.	July 1, 1922	0.4	†6.2
Army Base	A-27	Army	Sept. 9, 1922	0.4	26.4
Lovells Island	A-28	Army	Sept. 9, 1922	0.5	8.7
Hog Island	A-29	Army	Sept. 9, 1922	0.5	11.6
Cunard Pier No. 3—East Boston	BA-1	B. & A. R. R.	Oct. 14, 1922	2.0	24.5
Bridge No. G. S. 743—Chelsea Creek	BA-2	B. & A. R. R.	Oct. 14, 1922	2.0	28.0
Boston Navy Yard	YD-105	Navy	Oct. 15, 1922	1.3	26.8
Destroyer Base—Squantum	YD-106	Navy	Oct. 15, 1922	0.0	12.0
Fort Point Channel	ASR-1	American Sugar Refining Co.	Feb. 15, 1923	......	......

*Board in horizontal position.
†Board changed from horizontal to vertical position December 15, 1922.

The results of the inspection of test blocks from these boards were as follows:

NH-1—The *Limnoria* attack on these blocks was fairly heavy, the blocks being destroyed to a depth of about ¼-inch in a year. Many of the blocks had a heavy deposit of mud but specimens of *Mytilus;* Algae as well as *Balanus;* and Bryozoa were often in evidence. In spite of the presence of the two latter no signs of shipworms were found.

BM-1—Two specimens of *Limnoria* and one small specimen of *Balanus* were the only organisms which appeared on the blocks during the 13 months during which the board was immersed.

BM-2—A few specimens of *Limnoria* appeared on five or six of the blocks but no other life.

BM-3—*Limnoria* appeared on nearly all blocks, at times several hundred on each face. The damage exceeded ⅜-inch in the 13 months in which the board was in service. No other organism appeared.

BM-4—No borers were found and there was a considerable deposit of mud on all the blocks. The accompanying organisms found were *Mytilus*, pelecypods with some specimens of *Balanus* and Bryozoa.

A-27—A few specimens of *Limnoria* were found on one block. Otherwise no life appeared.

A-28—A few specimens of *Limnoria* were found in some blocks. Ac-

companying organisms were *Mytilus*, Algae, a few specimens of *Balanus* and Bryozoa (*Lepralia*).

A-29—A comparatively small number of *Limnoria* never exceeding 100 were found on most of the blocks. The accompanying organisms were *Balanus* and Bryozoa (*Lepralia* and *Bugula*) in small numbers.

BA-1—*Limnoria*, never more than 50 individuals, were found in some blocks with occasionally *Mytilus* representing the accompanying organisms.

BA-2—Specimens of *Limnoria* and a rather heavy growth of *Tubularia* appeared on a few blocks in the summer of 1923.

YD-105—*Limnoria* only, in small numbers, was found until the late summer of 1923 when the blocks were damaged to a depth of ¼-inch. Nudibranchs of the genus *Aeolis* which were found indicate that the degree of pollution is probably not sufficient to explain the absence of shipworms in numbers.

A piece of 8 by 8 inch timber taken from a flume which carries the circulating water return from the condenser plant was examined. The flume has been in service between 20 and 30 years and the water temperature varies between 50 and 70 degrees Fahr. The specimen which was typical of the structure was damaged by *Limnoria* for about half its depth; the timber in the top of the flume was in excellent condition.

Another specimen taken from the outer end of the shipbuilding ways between Piers 6 and 7 showed a severe *Limnoria* attack. This specimen also contained one shipworm burrow of rather recent date, about 9 in. long. Both ends of the tube had been eaten away by *Limnoria*.

YD-106—A very few specimens of *Limnoria* accompanied by *Balanus* and Bryozoa were found on the blocks removed late in the summer of 1923.

ASR-1—No life of any kind appeared during the 6 months that this board was in service.

Salinity and temperature observations made by the Boston & Albany Railroad at Cunard Pier No. 3 at East Boston and at Bridge G J 743, Chelsea, are shown in Figs. 50 and 51, respectively, and observations of salinity, temperature, oxygen content and hydrogen-ion concentration made by the American Sugar Refining Co. are shown in Fig. 52.

Methods of Protection

Protection of timber exposed to marine borers has never been considered necessary, although there are some creosoted piles in service.

Substitutes for Timber

Concrete—The following records of concrete structures are taken from a special report on structures belonging to the Navy Department at the Charlestown Navy Yard.

> Pier 1 is approximately 400 by 150 feet and consists of a face wall made up of concrete arches 24 feet wide and 40 feet span. The piers supporting the arches are approximately 12 feet by 38 feet and extend 30 feet below M.L.W., where they rest on a pile foundation. Reinforced concrete curtain walls were constructed on the inside of the arches extending from the extrados of the arch to the surface of the riprap filling, these curtain walls, together with the arch piers, forming a retaining wall to confine the filling material which forms the central portion of the pier.
>
> The pier was built in two sections, the outboard in 1902 and the inboard (consisting of 4 arches and piers) in 1903.
>
> The principal repairs on this pier have been made as follows:

1907—Reinforced concrete curtain walls were reinforced by a close row of wood piling.

1911—Five concrete arches in outboard section were repaired by reinforced concrete girders and 24-inch I-beams and a mass concrete retaining wall was built behind a part of the original wall.

1919—Faces of piers and arches repaired by the use of Gunite (Dewey Cement Gun Company method). This contract was abrogated because in the work of cutting away poor portions of the concrete the deterioration was found to extend much deeper than originally expected, requiring such large masses of new concrete to replace the old that it was deemed inadvisable to complete the work by the Cement Gun method. A granite facing was built for replacement of the deeply eroded section.

The concrete used in the original construction was a 1: 2: 4 mixture, Lehigh and Alpha brands of cement being used on the outboard and Catskill on the inboard ends; the aggregate was screened gravel and a good quality of sand. Below M.L.W. the concrete was deposited within well constructed plank forms by means of a metal tremie, a dry mixture without water being used, the tremie being well charged before discharging and frequently moved.

This pier is exposed at times on the end to a one or two mile per hour current, and also to slight wave action. It is exposed to abrasion from floating debris and considerable ice during the winter months. Much of the damage is undoubtedly due to ice and frost; some damage is also attributed to vessels lying alongside the pier.

All concrete structures at the Navy Yard are exposed to a range of temperature from about 90° Fahr. in the summer to a normal minimum of 0° Fahr. in the winter, with freezing conditions almost daily during the three winter months.

Pier No. 1 is at present in poor condition and extensive repairs may be necessary.

Quay Wall, West Inboard Side Pier No. 1—This is a reinforced concrete wall approximately 700 feet long, 45 feet high (32 feet 5 inches below M.L.W.) and 3 feet thick. The way is backed by a heavy timber crib filled with rock. The lateral crib timbers are notched and extend into the wall.

The reinforcement consists of heavy galvanized triangular mesh expanded metal and is placed near the face of the wall.

The wall was built in 1900 by the Fitchburg Railroad and repaired in 1915 by the Boston & Maine Railroad, lessee (the agreement between the Fitchburg Railroad Company and the United States being that any repairs to the wall should be made by the railroad company).

The concrete above M.L.W. was 1: 3: 6 mixture, below M. L. W. 1: 2: 3 mixture, gravel being used for the aggregate.

In that portion of the wall below M. L. W. concrete was deposited by the use of bottom dump buckets, the concrete flowing through the meshes of the expanded metal to form the face. The forms of heavy matched timber were bulkheaded into sections, but are reported not to have been tight, and much difficulty was reported in depositing concrete and in the maintenance of the reinforcement in proper position; a rather dry mixture was used above M.L.W. This wall at present shows considerable deterioration both above and below mean high water.

There is at present along the entire water front at this station a large accumulation of fuel oil, which forms a permanent coating on all structures between the range of extreme high and low tides.

Hingham Ammunition Depot.—The concrete pier forming a dock at the Hingham Naval Ammunition Depot for all vessels having business with this station is "U" shape, 13 feet in height and built on a timber platform (Elev. 102.3 feet) with pile supports. The pier, built in 1910, is situated on the Weymouth Back River, a salt tidal stream discharging a considerable quantity of fresh water. The river freezes over in the winter months, and there is heavy ice in the dock and on the surrounding walls. The amount of chemical waste, etc., that is discharged by this river is small. There is a maximum current in the river of from 4 to 5 miles per hour.

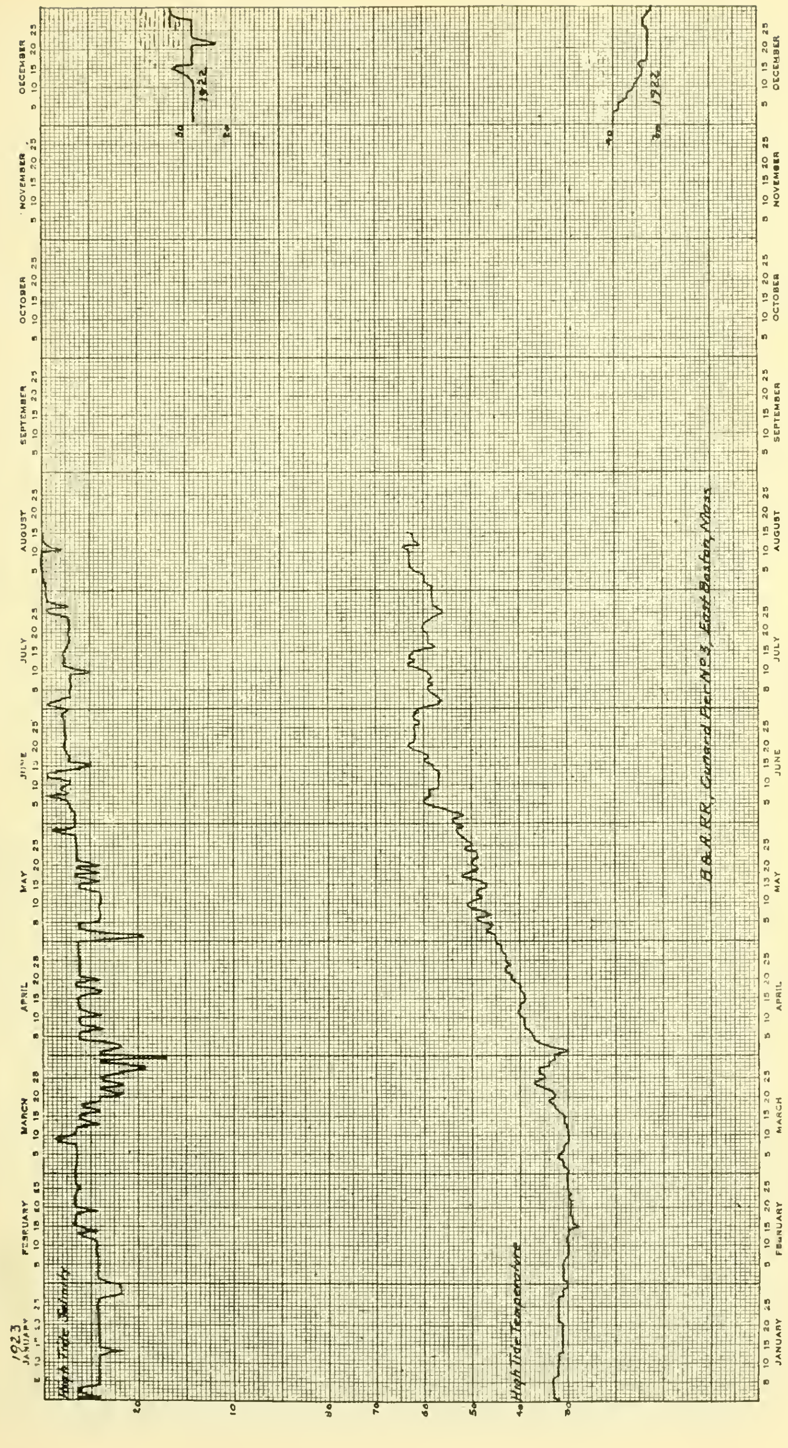


Fig. 50—Salinity and Temperature Observations, Cunard Pier No. 3, East Boston, Mass.

Timber Work.—The timber platform and piles are in apparently good condition, no signs of any deterioration being noticeable except in the tops of some of the fender piles along the dock walls, which are decayed.

Easterly Dock Wall.—The easterly wall is in good condition, showing only at isolated points any signs of scaling on the face of the wall.

Southerly Dock Wall.—This wall shows deterioration of the concrete for practically its entire length (76 feet) and for a vertical distance of 4 feet 6 inches, which is the distance between the timber platform and the 8-inch waling pieces between the fender piles.

The depth of this deterioration is from 2 inches to 1 foot. Above and in close proximity to the wales are several isolated spots having a total area of 40 square feet where the concrete has scaled off from 3 inches to 6 inches in depth. On the entire face there is a scale of from 1 inch to 2 inches in thickness that is loose in many places. The back of this wall has an area of 10 square feet where the concrete has been eroded 4 inches to 6 inches. There is a crack extending completely through this wall at approximately 30 feet from the westerly end.

Westerly Dock Wall.—This wall shows deterioration of concrete along its entire length (100 feet) below the waling pieces from 3 inches to 1 foot in depth. Above the waling pieces are a number of spots having a total area of 70 square feet where the concrete has scaled off from 2 inches to 6 inches in depth. There are three cracks extending entirely through this wall about 30 feet apart. The back of this wall shows erosion in several places, with a total area of 30 square feet and from 2 to 10 inches in depth. Much of the wall shows signs of scaling.

North End Wall.—The concrete for its entire length (14 feet 6 inches) and for an average height of 7 feet is eroded from 1 foot to 2 feet in depth.

Westerly Return Wall.—(27 feet long and 6 feet high). The concrete is badly eroded over an area of 90 to 100 square feet from 6 inches to 1 foot back from the face of the wall.

The easterly dock wall mentioned above was repaired with gunite in 1918 by the Dewey Cement Gun Co., and the other defective walls were repaired in the same year with the steam atomizer process by the Harold F. Brown Co. In 1923 all walls except the easterly one again needed repairs.

Two structures, the seawalls at Fort Heath and Fort Warren, are reported by the Army as follows:

Seawall at Fort Heath.—This wall was built in 1910 and 1911 to hold the toe of the granite slope pavement which protects the foot of the bluff at this place. It was founded at the mean high water line on hardpan, into which it extended about 3 feet, was some 600 feet long, 3 feet high and 2½ feet thick. It was constructed of 1: 2: 4 concrete, hand mixed, and poured continuously in sections about 8 feet long. The materials were Alpha cement, pit sand, crushed trap rock, and salt water. About half of the wall was built with stones from the beach set in the face. It was exposed to the severe storms from the east and northeast, sweeping over a beach covered with stones of all sizes.

In 1912 it was reported that most of the sections into which the wall was divided by vertical construction joints showed some pitting, but in the majority no real injury had resulted.

In 1916 it was reported that out of the more than forty sections, seven were broken and worn down to the level of the shore, and a number of others were badly pitted at about the line of high water. In 1923 all but a few of the sections have been broken and worn down to the grade of the beach, and all those standing are badly broken and eroded on the face.

Seawall at Fort Warren.—In 1918 a concrete seawall was built at Fort Warren, as well as concrete foundation backing, and paving for a granite seawall. The wall is about 140 feet long, 7 feet high, including its foundation, and averages 3 feet thick. Above the foundation, the wall was built in alternate sections 10 feet in length with a recess in the end of each section, the 10 feet spaces between sections being filled in afterwards. All sections were monolithic.

The wall and paving were 1: 2: 4 concrete made of cement to pass specifications of the Bureau of Standards, salt water sand, salt water gravel and

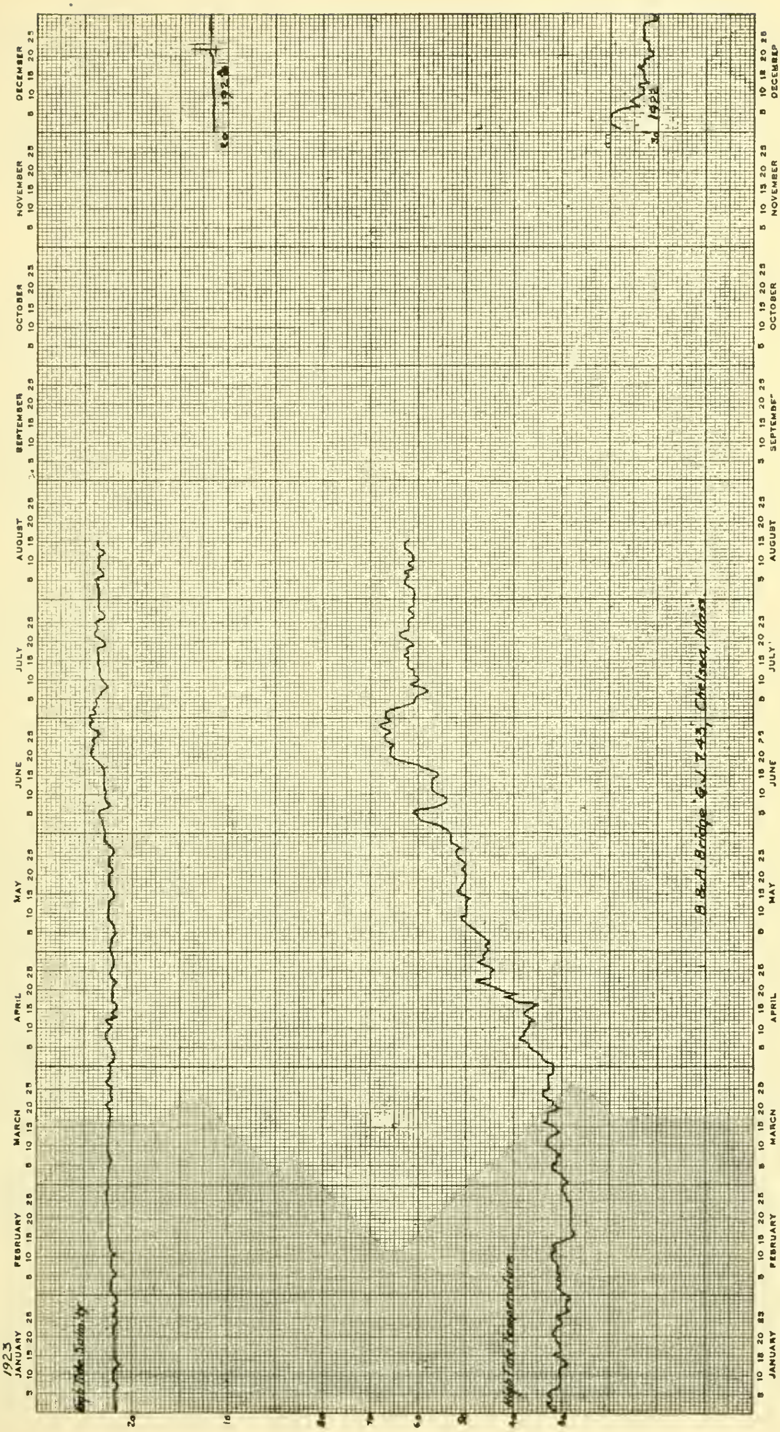


Fig. 51.—Salinity and Temperature Observations, B. & A. R R. Bridge No. 743, Boston, Mass.

salt mixing water. The wall was founded on earth about 1 foot above mean high water, and granite riprap placed in front of it. The exposure to wave action is very slight.

On a recent inspection, no evidence of deterioration was seen in the concrete wall or paving.

The construction records of the Boston Army Supply Base are as follows:

Construction authorized April 7, 1918.
Construction contract awarded April 9, 1918.
Construction work started April 10, 1918.
Construction work completed June 5, 1919.

Wharf.—The wharf is 5,473 feet long.

General type of substructure construction.

Woodpiling cut off at mean high water, bearing girder and beam construction of reinforced concrete with reinforced concrete floor slab. 22,857 wood piles for most part hard southern pine with no protection.

Wharf Sheds.—1,638 feet by 100 feet, carried on 16,000 wood piles.

Pier Sheds.—Each building 924 feet by 100 feet, carried on wood piling. The longitudinal walls adjacent to the water in the north and south sides of structure are carried partly on precast concrete sheet piles and partly on Raymond piles driven just inside sheet piling.

1,115 feet concrete sheet piling.
6,288 Raymond concrete piles.
4,196 wood piles.

Specification for concrete calls for a 1: 2: 4 mixture. Amount of cover over reinforcing steel is shown on plans as 2 inches from perimeter of steel both in bottom and sides of beams and on bottom of slabs, and it is presumed that this was actually followed in construction. The main storehouse rests on concrete columns.

Totals.—

Wood Piles	43,053 ft.
Concrete Sheet Piles	1,115 ft.
Concrete Raymond Piles	6,288 ft.

A report on the condition of these structures made in 1923 is as follows: "A careful inspection of the concrete piling and girders of this Base was made, and the following report is submitted. The concrete piles are in excellent condition with the exception of a few under the North Pier shed, which are slightly streaked with rust. The outside concrete girders next to the cap-log on the dock at the North and South Pier sheds showed rust streaks from 2 to 9 feet long in several places. In many of the girders the reinforcement rods are exposed for six feet. The outside girders of the wharf shed are in better condition than those of the pier sheds, but there are signs of rust streaks and the rods are visible in places. From an examination of the girders in the vicinity of the exposed rods, it would appear that the reinforcing had a 1-inch cover. In a few places on the bottom of these girders, the rods were on the surface of the concrete, and apparently did not have a cover. The conditions herein described were found above high water, although the girders are exposed to the water from time to time in heavy weather, and when the tide is unusually high. The most of the interior girders are still covered by the wooden forms used in construction, but in the places that are exposed the girders are apparently in excellent condition, with no sign of rust streaks appearing, and all of the rods well covered."

Conclusions

Practically all concrete structures reported show deterioration and most of them severe damage, and while in the light of present knowledge of concrete construction, improvements in the quality of concrete could undoubtedly be made, it seems very questionable whether Portland cement

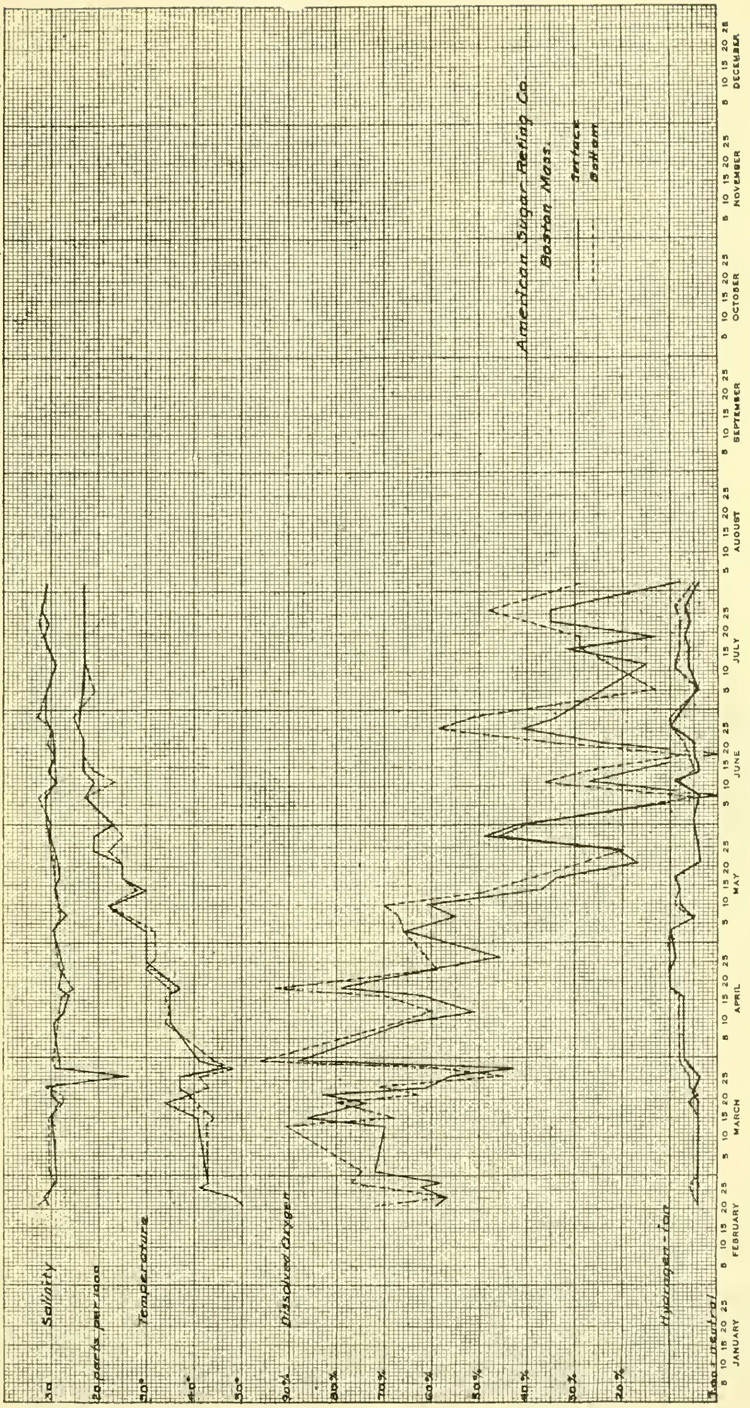


FIG. 52.—SALINITY, TEMPERATURE, OXYGEN CONTENT AND HYDROGEN-ION CONCENTRATION OF THE WATER AT AMERICAN SUGAR REFINING CO.'S PIER, BOSTON, MASS.

concrete without mechanical protection, such as granite facing, and a binding medium which will better resist chemical attack can be expected to give long life.

Limnoria attack, while not heavy at any point, will cause destruction in time. Results obtained from test block inspection do not indicate the probability of serious damage by shipworms, though these animals are present in the harbor.

BUZZARDS AND NARRAGANSETT BAYS

Description

The shore line of both Buzzards, (Fig. 53), and Narragansett, (Fig. 54), Bays is bold and generally rocky, with stretches of sand beach. The pre-

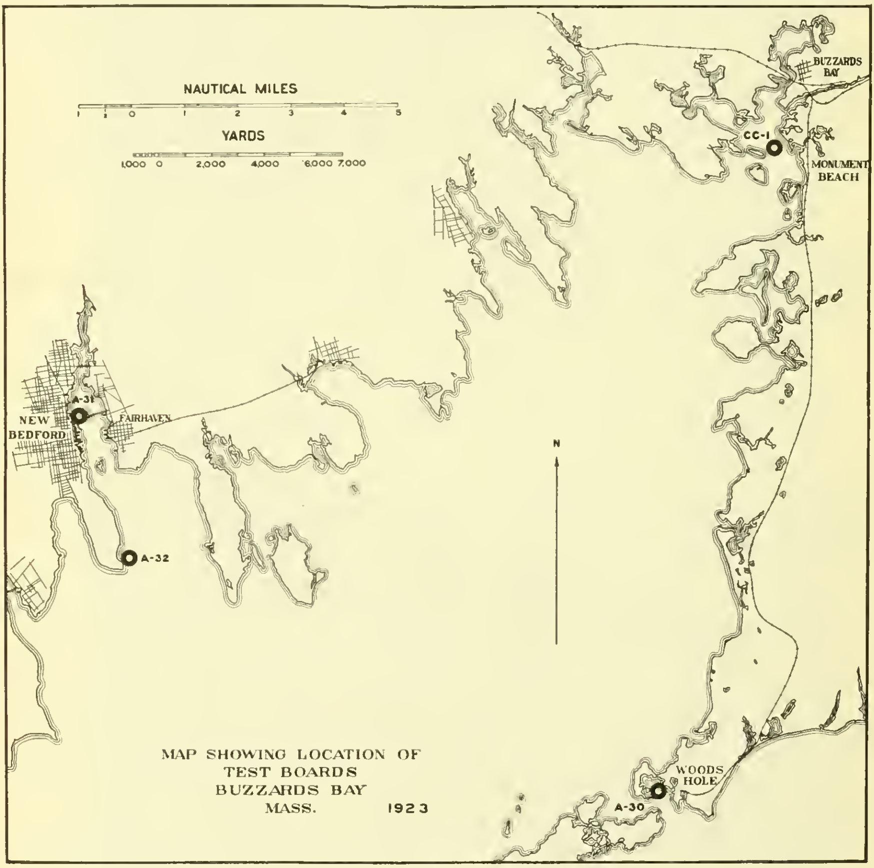


FIG. 53

vailing winds are northwesterly in winter and southwesterly and southerly in summer, but are subject however to many variations at all seasons. In winter drift ice is usually to be found. In 1908 the temperature of the water at Woods Hole ranged from 30 degrees Fahr. in February to 70 degrees Fahr. in July and August. The water of Buzzards Bay in the

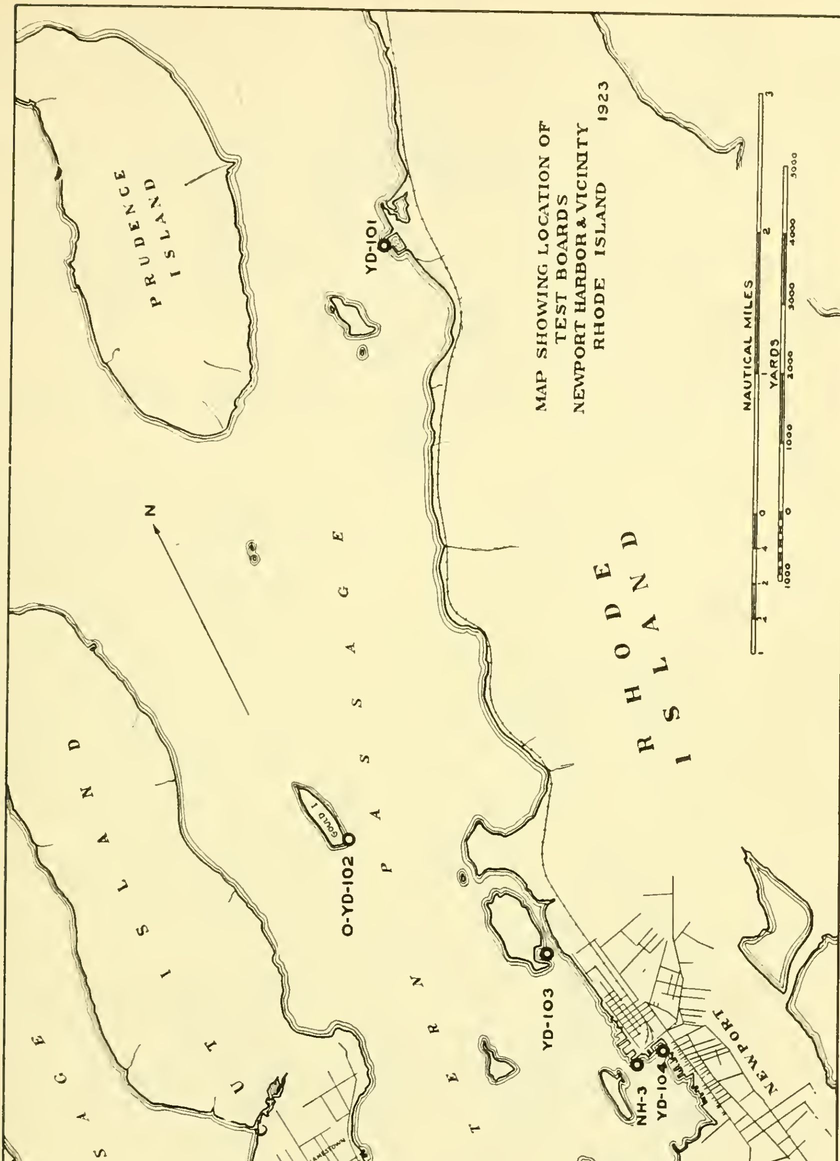

MAP SHOWING LOCATION OF
TEST BOARDS
NEWPORT HARBOR & VICINITY
RHODE ISLAND
1923
PRUDENCE ISLAND
CONANICUT ISLAND
WESTERN PASSAGE
EASTERN PASSAGE
RHODE ISLAND
JAMESTOWN
NEWPORT
THE NECK
GOULD I.
N
YD-101
O-YD-102
YD-103
NH-3
YD-104
O-A-33
NAUTICAL MILES
YARDS

FIG. 54

vicinity of the Cape Cod Canal was slightly warmer, the temperature reaching $71\frac{1}{2}$ degrees Fahr. in August.

Buzzards Bay is the approach to New Bedford Harbor and to the entrance of Cape Cod Canal. The mean rise and fall of tides is 4 feet.

Woods Hole is a narrow passage leading between numerous rocky shoals from Vineyard Sound to Buzzards Bay between the mainland and Nonamesset Island.

The Cape Cod Canal which connects Buzzards Bay with Cape Cod Bay is, including the approach channel, $11\frac{1}{2}$ miles in length, and has a least depth of 22 feet. The bottom width varies from 100 to 300 feet. The average velocity of the current at midstream is 3.6 knots. The canal has never been closed by ice but the Buzzards Bay approach has been.

New Bedford Harbor is located on the northwestern side of Buzzards Bay. The approach from the bay and the entrance to the harbor are obstructed by ledges and shoals. A channel 300 feet wide has been dredged to a depth of 25 feet.

The entrance to Narragansett Bay is between Brenton Point, the southwestern point of Rhode Island on the east and Point Judith Neck on the west. The bay is approximately 16 miles in length from the entrance to its northern extremity at the mouth of the Providence River. The greatest observed velocity of the tidal current is 1:3 knots per hour and the mean rise and fall of tide is 3.5 feet at the entrance and 4.7 feet at Providence.

Newport Harbor, (Fig. 54), is located on the eastern side of the Eastern Passage of Narragansett Bay about $3\frac{1}{2}$ miles above the entrance to the Bay, and is divided by Goat Island into an inner and outer harbor. The outer harbor is on the western side of Goat Island, between Rose Island on the north and Fort Adams on the south. The depths range from 40 to 60 feet. The inner harbor is on the eastern side of Goat Island and extends along the waterfront of the city of Newport. The northern portion has been dredged to a depth of 18 feet; the southern portion to 13 feet.

Fall River, (Fig. 55), is at the head of Mt. Hope Bay at the mouth of Taunton River. The depth at the wharves ranges from 10 to 25 feet.

Warren, about $2\frac{1}{2}$ miles above the mouth of the Warren River, has a channel of 10 feet minimum depth leading up to it.

Providence River is the approach to the Port of Providence, (Fig. 55), located about 7 miles from its mouth. The approach channel has a depth of 30 feet and the harbor area is being dredged to that depth. At Providence below the bridges the wharves have depths ranging from 10 to 30 feet. Tidal currents are not strong and generally follow the direction of the channel. In severe winters the river is closed to navigation for short periods.

Marine Borers

Past History—Both shipworms and *Limnoria* are present throughout this territory. The Lighthouse service has experienced considerable trouble with attacks by borers on their dolphins and buoys in Buzzards Bay and their wharf at Woods Hole. The dolphin piles specifically reported were of creosoted white oak (no record of treatment) and were completely destroyed in two years. Creosoted cedar spar buoys are said to last only three years, and treated oak piles in the wharf at Woods Hole five years. Heavy damage by marine borers has occurred in the past to waterfront structures at Fall

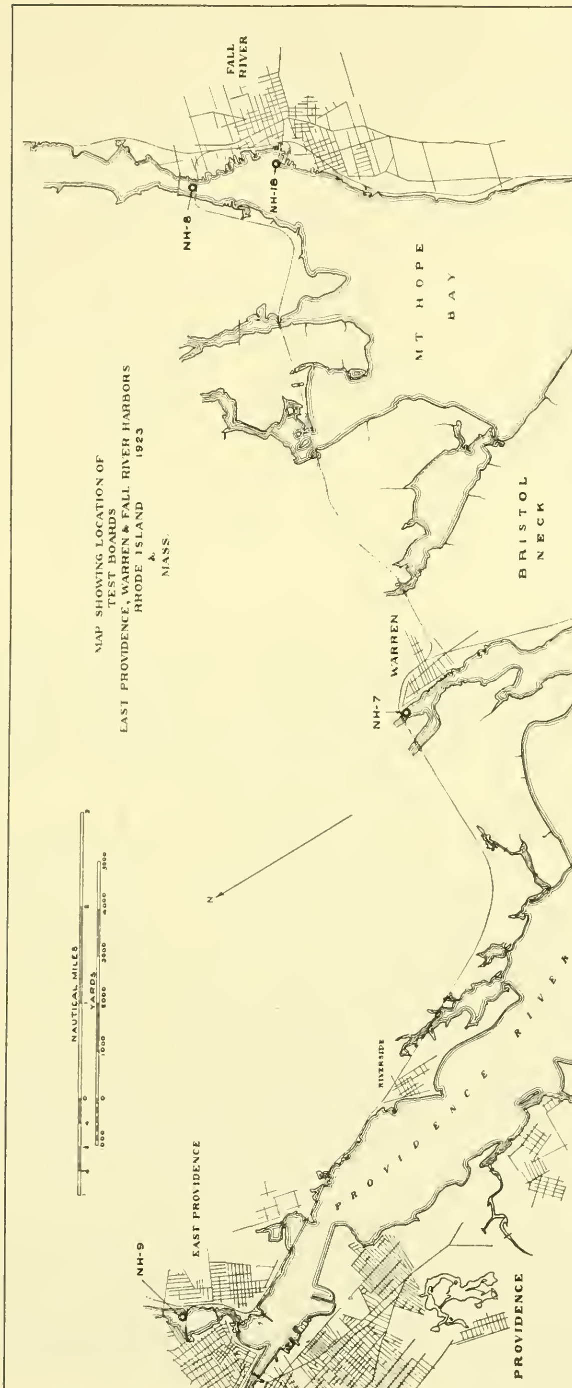

MAP SHOWING LOCATION OF
TEST BOARDS
EAST PROVIDENCE, WARREN & FALL RIVER HARBORS
RHODE ISLAND 1923
&
MASS.
FALL RIVER
NH-8
NH-18
MT HOPE
BAY
BRISTOL
NECK
WARREN
NH-7
NAUTICAL MILES
YARDS
N
RIVERSIDE
EAST PROVIDENCE
NH-9
PROVIDENCE RIVER
PROVIDENCE

Fig. 55

River. In other parts of this territory unprotected timber is estimated to last 6 to 10 years although there are some wharves of record which have stood 20 years without renewal of piling.

Committee Investigations—The test boards installed are shown in the following table:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Woods Hole—Bureau of Fisheries Wharf	A-30	Bureau of Fisheries (Dept. of Commerce)	Oct. 2, 1922	2.5	9.2
Buzzards Bay entrance to Cape Cod Canal (Dolphin No. 164)	CC-1	Cape Cod Canal	June 1, 1923	1.0	15.0
New Bedford—Duffs Coal Wharf	A-31	Army	Oct. 14, 1922	0.5	17.5
New Bedford—Fort Rodman	A-32	Army	Oct. 14, 1922	0.5	7.2
Newport—Long Wharf	NH-3	N.Y.N.H. & H.R.R.	June 1, 1922	0.0	10.0
Newport Government Landing	YD-104	Navy	Oct. 15, 1922	2.0	7.0
Newport—Constellation Dock	YD-103	Navy	Oct. 15, 1922	1.0	8.0
Newport—Gould Island Wharf	YD-102	Navy	Oct. 15, 1922	2.0	12.0
Newport—Melville Coaling Pier	YD-101	Navy	Nov. 1, 1922	0.0	7.1
Fall River—New England Steamship Co. Pier	NH-18	N.Y.N.H. & H.R.R.	Aug. 1, 1923	2.0	18.0
Fall River—Slades Ferry Bridge	NH-8	N.Y.N.H. & H.R.R.	June 1, 1922	0.5	20.0
Warren—Intake Pier	NH-7	N.Y.N.H. & H.R.R.	June 1, 1922	0.0	*0.1
Providence—India Pt	NH-9	N.Y.N.H. & H.R.R.	June 1, 1922	0.3	23.7
Dutch Island Harbor	A-33	Army	Oct. 14, 1922	0.5	9.6

*Board in horizontal position.

The inspection of test blocks and specimens gave the following results:

A-30—This board was immersed too late for the 1922 season of activity and consequently no shipworms were found until block 20 was removed, August 1, 1923, in which two specimens of *Teredo navalis* appeared. Block 22 contained 1, blocks 23, 30, and 24, removed October 1, 40 specimens of *Teredo navalis*. Attack by *Limnoria* was of medium intensity. Associated organisms were *Balanus,* Bryozoa and Algae.

CC-1—4 specimens of *Teredo navalis* ranging in length from 5 to 20 mm. were found in block 3, removed September 1, 1923, and 100± with lengths from 1 to 2 inches were found in block 4, removed October 4. None appeared in the monthly (center) blocks. No *Limnoria* activity was in evidence. Associated organisms were *Balanus* and Bryozoa.

A-31—20 blocks from this location were examined and while the appearance of *Balanus* and Bryozoa indicated favorable conditions for shipworms none were found. Attack by *Limnoria* was severe.

A-32—No life of any kind appeared on the first 14 blocks. A few *Balanus* were found on block 15, removed June 1, 1923, which increased in number to about 100 on the succeeding blocks. Activity by *Limnoria* was light. The last block examined (No. 20) was removed August 16, 1923. This showed a trace of *Limnoria* activity, of Bryozoa and about 100 specimens of *Balanus.*

NH-3—The first shipworm was found on block 5, removed August 15, 1922, just beginning to form the burrow. Shipworms, identified as *Teredo navalis,* ranged in number from 3 to 50 on each of the succeeding blocks. The old type of testboard was continued in service, all of the original and 9 replacement blocks, the last one removed October 15, 1923, having been examined. Activity by *Limnoria* was intense. Of the associated organisms only Bryozoa was found.

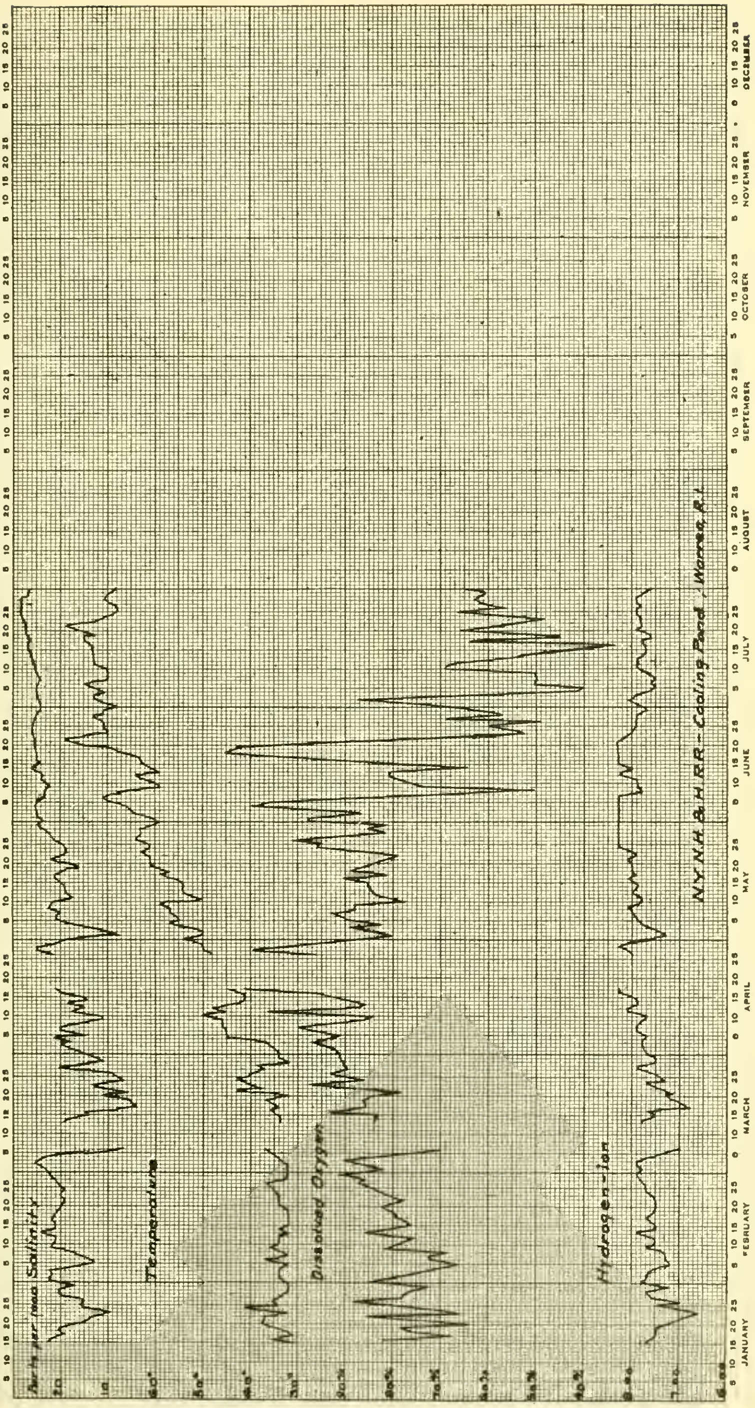


FIG. 56.—SALINITY, TEMPERATURE, OXYGEN CONTENT AND HYDROGEN-ION CONCENTRATION, N. Y., N. H. & H. R.R. COOLING POND, WARREN, R. I.

YD-104—No shipworms were found. *Limnoria* action was of medium intensity. Associated organisms were *Mytilus*, Bryozoa, Algae and Anomia. 20 blocks were examined between November 1, 1922, and August 16, 1923.

YD-103—20 blocks were examined, the removals having been made between November 1, 1922, and August 16, 1923. No shipworms were found and the activity of *Limnoria* was negligible. Associated organisms were *Mytilus*, Bryozoa and Algae.

YD-102—Same as YD-103 with the addition of Anomia among the associated organisms.

YD-101—19 blocks were examined between the dates November 15, 1922, and August 16, 1923. No shipworms were found but *Limnoria* action was heavy. Associated organisms were *Balanus, Mytilus* and Algae.

The examination of a section of untreated timber taken from underwater cross-bracing placed in Melville Coaling Depot, in 1915 and removed in August, 1922, showed complete destruction by *Teredo navalis* and heavy attack by *Limnoria.*

NH-18—This board is of the revised type and two sets of blocks were removed September 1, and October 1, 1923, respectively. Shipworms did not appear on the monthly (center) blocks but were numerous on the others as many as 100± being found in the second block. These were identified as *Teredo navalis.*

NH-8—A few specimens of *Teredo navalis* were found in block 5, removed August 15, 1922, their number increasing to 30-40 in each of the succeeding blocks 6 to 8 inclusive. Block 9 removed October 16, was well filled and block 10 removed October 31, completely filled with *Teredo navalis.* Complete destruction was effected in three months time. *Limnoria* action was severe in the first few blocks but diminished in intensity with the increase of shipworm attack. Associated organisms were *Balanus*, Bryozoa and Algae. At the time of the removal of block 22, May 1, 1923, the board together with the remaining original and the replacement blocks was carefully examined. From this examination it was found that the end of the season of activity occurred prior to September 1. A new board of revised type was installed June 27, 1923. *Teredo navalis* appeared on blocks 3 and 3C of the new board, removed September 1, the center block having been in the water one month. Block 4C, removed October 5, contained 100± specimens of *Teredo navalis.*

NH-7—The first appearance of *Teredo navalis* occurred on block 4, removed August 1, 1922. Block 6, removed September 1, was completely perforated by the young organisms and destruction progressed even more rapidly than at NH-8. The board together with remaining original (Nos. 17-24) and replacement blocks was removed February 15, 1923, and a new board of revised type substituted. From an examination of the old test specimen, the end of the season of activity was determined to have occurred between August 15 and September 1. The first *Teredo navalis* to be found on the new blocks appeared on block 4, removed September 1, 1923. Associated organisms were *Ostrea, Balanus* and Algae. *Limnoria* action was inconsiderable.

NH-9—*Teredo navalis* first appeared in block 12, removed December 1, 1923. From 1 to 4 specimens were found in each of the succeeding blocks to and including block 27. Block 27, being the third replacement block, was

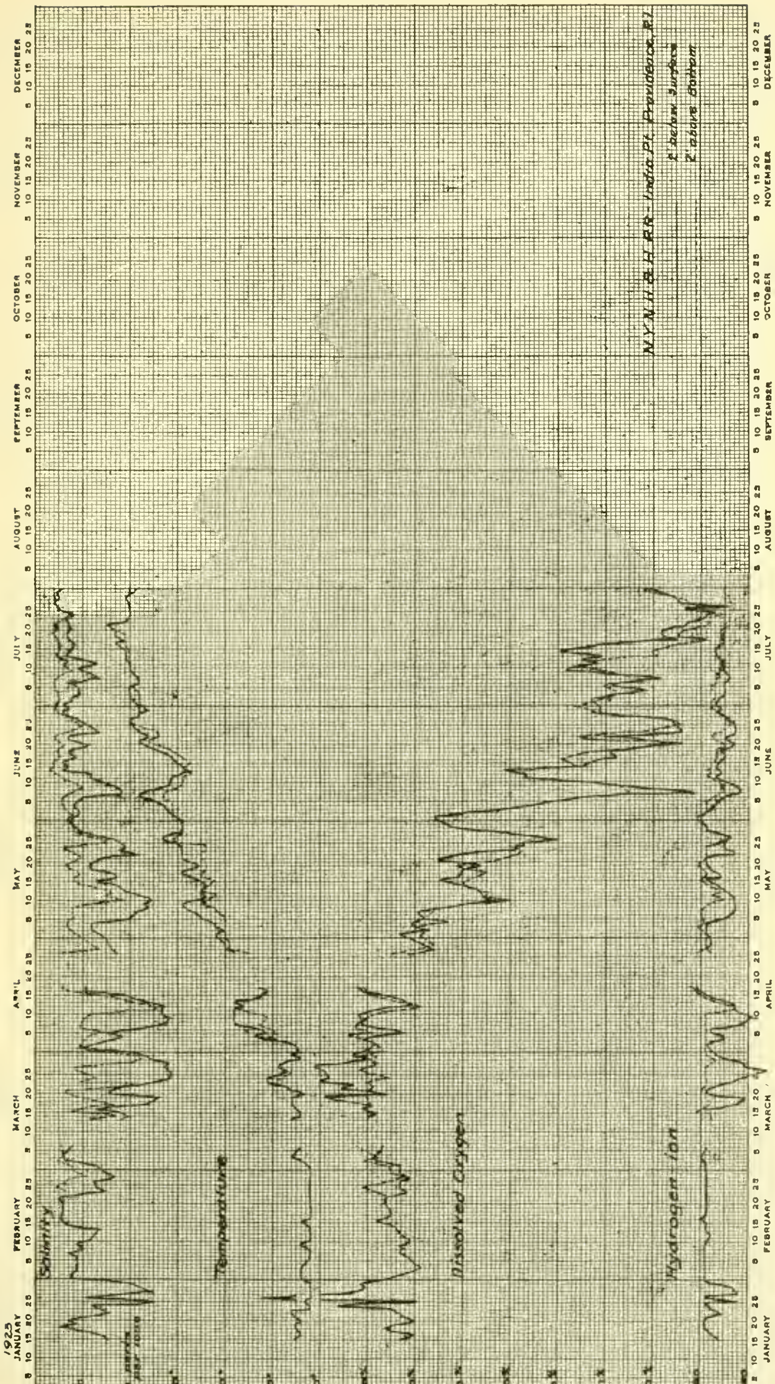


Fig. 57—Salinity, Temperature, Oxygen Content and Hydrogen-ion Concentration, N. Y., N. H. & H. R.R. Pier, India Point, Providence, R. I.

placed in the water July 15, 1922. None of the remaining replacement blocks contained shipworms. There was no *Limnoria* action. Associated organisms were *Balanus*, Bryozoa and Algae.

A-33—Twenty blocks from this board were examined and although the associated organisms indicated that conditions were favorable for shipworms, none were found. This may be accounted for by the late date (October 14, 1922) on which the board was submerged. The last block was removed August 15, 1923, a little too early for the 1923 brood. A very light attack of *Limnoria* was in evidence. Associated organisms were *Balanus*, Bryozoa, *Mytilus* and Algae.

It is now safe to say that there is generally a period of immunity from shipworms in this territory of about ten months between September 1 and July 1, though the 1923 attack occurred later than that of 1922.

Chemical analyses of the water at Warren and Providence (India Point) were made daily and the temperature, salinity, oxygen content, and hydrogen-ion concentration at these two locations are shown on Figs. 56 and 57.

Salinity and temperature observations for the fiscal year ending June 30, 1923, recorded by the Bureau of Fisheries are shown on Fig. 58.

Experimental Field Tests

Tests of the protective qualities of copper wire and bands are being conducted by the New York, New Haven & Hartford Railroad, at Warren. Blocks bound with both wire and bands with different spacing ranging from ½ inch to 2½ inches were immersed on November 5, 1922. This method had in view its possible application to existing structures. The results of this experiment will be found in Chapter II, page 14.

Methods of Protection

The great majority of timber exposed to marine borers in this territory is unprotected which is surprising in view of the activity of both shipworms and *Limnoria*. Little or no service data of creosote, or other protection methods, are to be had from the territory. Some creosoted structures are in use and the experience of the Lighthouse Service with this method cited above should not be taken as representative of this district.

Substitutes for Timber

Concrete—The following report on structures at the Naval Station at Newport, R. I., was furnished by the Public Works Officer.

> "There are three concrete-timber structures at this Station, one at Rose Island, constructed in 1913, one at Melville Fuel Station, constructed in 1916, and one at the Training Station, constructed in 1919. Also a concrete pier at Gould Island constructed in 1919 and 1920. The structures at Rose Island and Melville are of the same type, reinforced concrete deck and columns, set on wood pile bents, 25 feet centers; piles are cut off at mean low water, and capped with yellow pine timber. The columns were precast, and allowed to season thirty days, summer season, before handling. The concrete mixture was one part of Lehigh cement, two parts of sand, and four parts of stone; clean fresh water was used for mixing. The sand used was composed to a large extent of quartz; stone, crushed granite; steel, deformed bars (exact type not known), minimum cover of steel 1½ inches. These structures are exposed to salt spray. The present condition is good. The structure at the Training Station consists of an enclosing plain concrete wall on pile and timber platform, the interior of pier filled with dirt. Wood piles are cut off at mean low water and the outside edge of platform protected

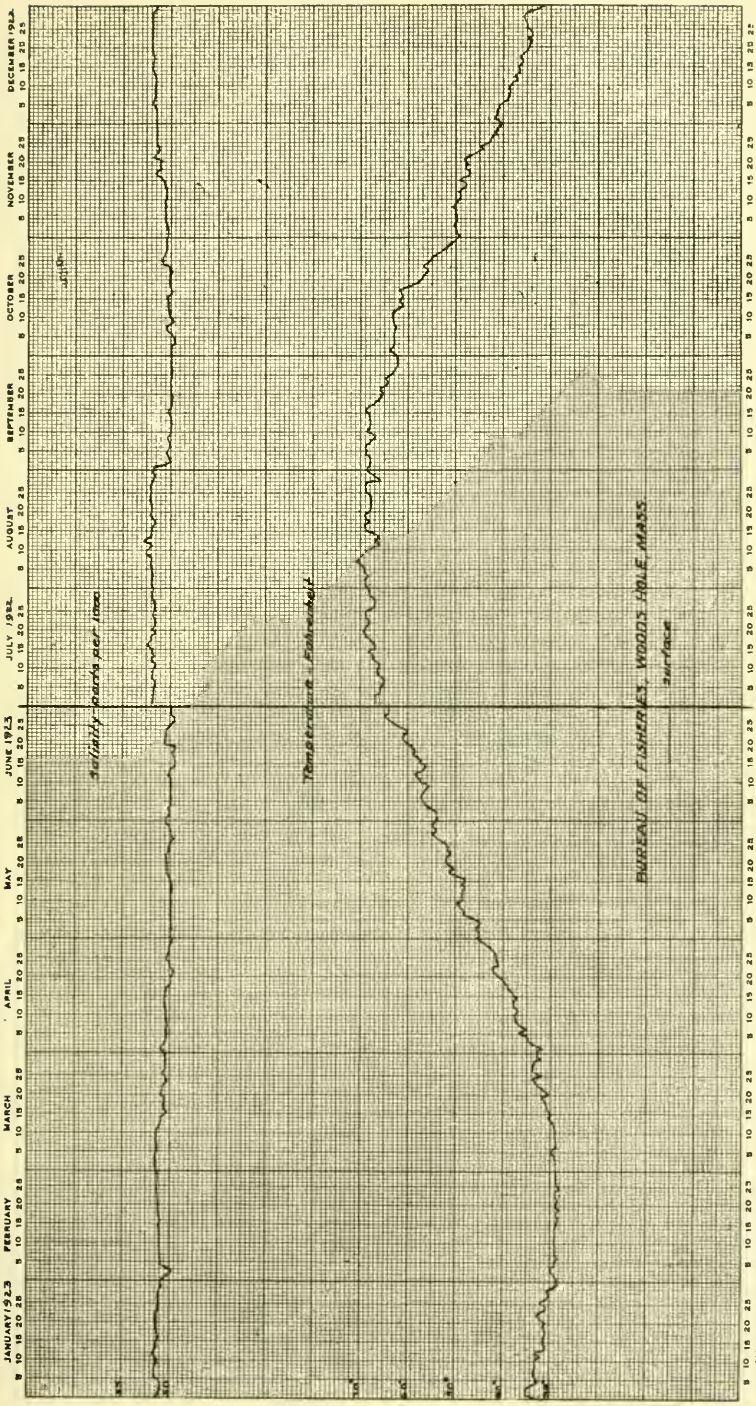


FIG. 58.—SALINITY AND TEMPERATURE OBSERVATIONS, WOODS HOLE, MASS.

by concrete sheet piles 12 inches thick. Sheet piles precast, 1:1½:3 mixture of Acme cement, quartz sand, crushed granite; plain round steel bars for reinforcing. Piles were allowed to season thirty days, summer season, and were driven with a 5,000 lb. drop hammer, no damage having been caused by driving. This structure is in good condition. The Gould Island pier consists of a reinforced concrete flat slab deck, 1: 2: 4 mixture, built on reinforced concrete piles, 1: 1½: 3 mixture; cement used, Lehigh; sand largely composed of quartz; stone, crushed trap rock; steel, plain cold twisted rods. Concrete piles were cast in the month of November, non-freezing weather, and were allowed to season for about five months. They were driven with a steam hammer to rock, a penetration of about three feet. In order to obtain lateral support, the spaces between piles were filled with riprap to about mean low water. This structure is greatly exposed to wave action and salt spray. It is in good condition.

"All concrete in these structures was covered during the period of curing, and kept wet; all forms used were of wood; reinforced steel was clean, and all construction joints were washed before joining new concrete. Concrete was poured in nonfreezing weather. The concrete in these structures is in good condition. In about four years after completing the Rose Island pier, rust spots began to show on the bottom of girders; at these places the rods were exposed, cleaned and re-covered with gunite. These rods were probably allowed to sag during construction. This pier is exposed to storms and wave action, and is of a design poorly adapted for this location, as lacking rigidity to resist vibration. These structures have not been installed a sufficient length of time to properly judge their suitability."

Metal Structures—The deck of main coaling pier installed at Melville in 1903 is supported by 48 inch steel plate girders, 48 feet 6 inches span, ⅜ inch web plate, 6 inches by 4 inches by ½ inch angles, 13 inches by ½ inch cover plate. The bottom of this girder is 7 feet above mean low water, and is subjected to salt spray. To prevent these girders from deteriorating, they have been cleaned, red leaded, and painted from time to time. In 1921 part of this steel work was sand blasted to gray metal, and a coat of gunite was applied, about ⅜ inch thick. The total cost of this work was 43.6 cents per square foot, of which 35.8 cents was for sand-blasting and chipping, and 7.8 cents for gunite. Due to vibration of the steel work caused by blows from ships striking against the sides of the piers, the gunite has in some places cracked away from the steel.

Conclusions

Service records and the investigations of the Committee indicate that structures in salt water in this territory may be attacked by borers and that all timber constructions of importance should be protected if they are to have a reasonably long life. The attack may easily be severe enough to cause destruction in two or three years.

The record of concrete is not especially good and the practice of facing concrete structures with granite as practiced by the New York, New Haven & Hartford Railroad undoubtedly adds greatly to the life of the structure.

LONG ISLAND SOUND (POINT JUDITH TO THROGS NECK)

Description

Long Island Sound is a region of boulders with very little natural change taking place in the shore line and shoals such as occurs on the outside coast of Long Island, where the beach is sandy and free from boulders. In ordinary winters ice forms in the western end of the Sound as far as Eatons Neck; in exceptionally severe winters it may extend to Falkners Island and farther eastward.

Fishers Island, (Fig. 59), about six miles long, is at the eastern entrance to the Sound. Silver Eel Pond, where the test board is located, is on the western end of the island, about five-eights mile northeastward of Race Point. The entrance is about 75 feet wide between jetties, with a depth of 16 feet diminishing to 14 feet inside.

Mystic River, (Fig. 60), has been dredged to a least width of 100 feet and a depth of 15 feet up to the town bridge at Mystic. Below the railroad bridge the current is less than one-half knot per hour. The mean rise and fall of tide at the location of the test board is 2.5 feet.

The Thames River, (Fig. 61), which flows into the Sound northwestward of the western end of Fishers Island, forms the harbor of New London.

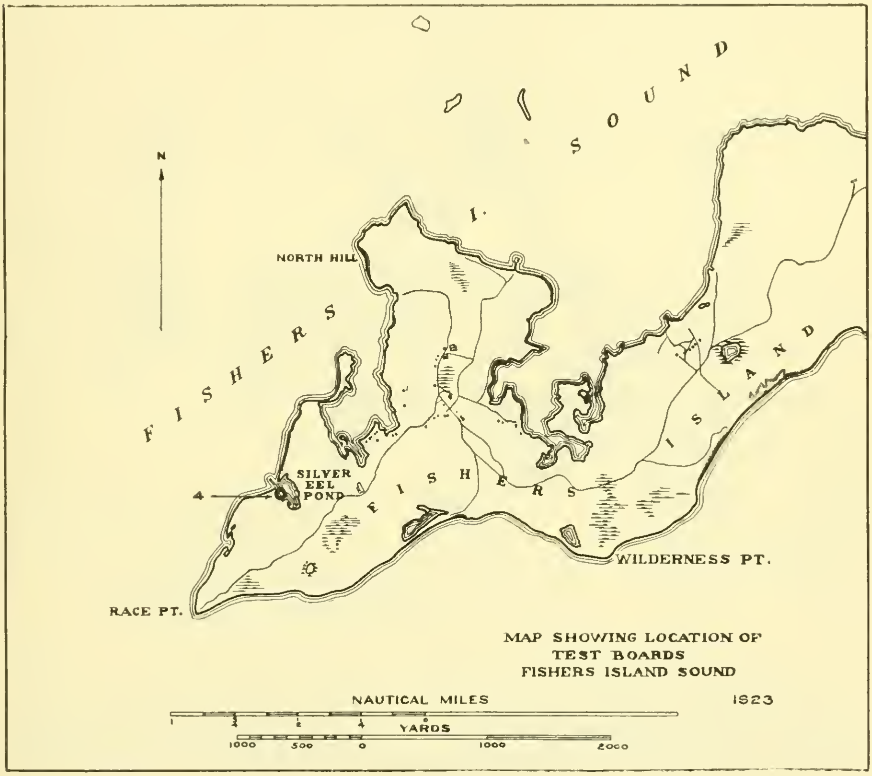


FIG. 59

This harbor has a dredged channel of 400 feet minimum width and 33 feet depth with a mean rise and fall of tide at New London of 2.5 feet. The depth alongside the wharves at low water ranges from 10 to 16 feet. The currents found in the Thames River are not strong, the velocity generally averaging from one-half to three-quarter knots, though two knots has been recorded at the Submarine Base. At the U. S. Naval Station (Submarine Base), 2 miles above New London, there is a minimum depth of 27½ feet, and at the coal receiving piers of the N. Y., N. H. & H. R. R. at Allyns Point, 5 miles above New London, there is a depth of not less than

22 feet at high water. Ice seldom forms below the Naval Station except close to shore where piers retard the current, though drift ice is sometimes driven in from the Sound in severe winters and has been known to extend to a distance above the mouth of the river of 1¾ miles.

The Fort Terry Wharf on Plum Island, (Fig. 62), has a depth of 15 feet at the outer end.

Greenport Harbor on Long Island, (Fig. 62), opposite the mouth of the Connecticut River, is formed by a breakwater on the northeast. The depths at the wharves range from 7 to 19 feet. The test board is located on the Texas Company's wharf, in 7.5 feet of water at mean low water.

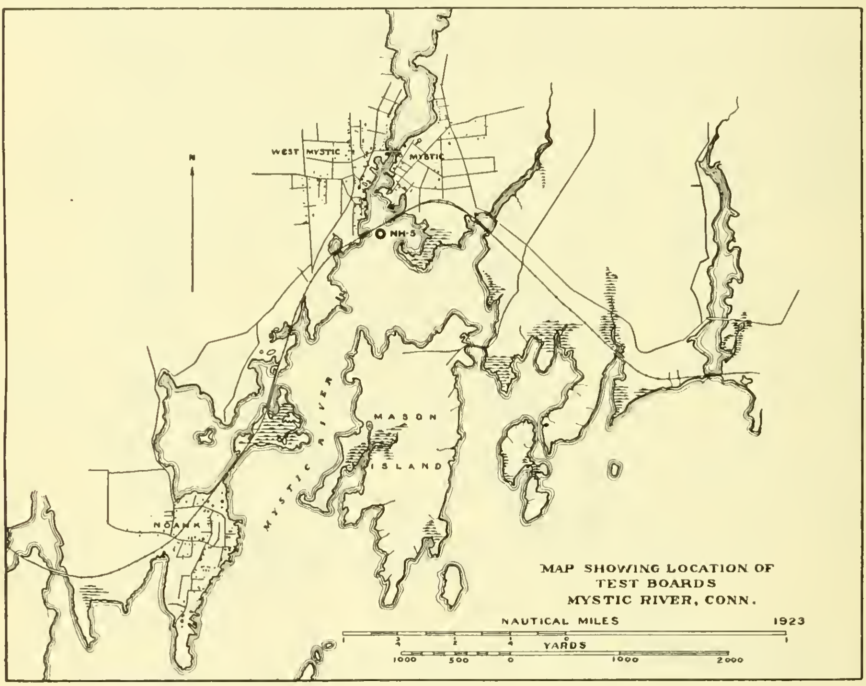


FIG. 60

Guilford Harbor, (Fig. 62), lies about midway between the mouth of the Connecticut River and New Haven Harbor. The test board is located about 1¼ miles up West River, where the mean rise and fall of the tide is approximately 3.2 feet.

New Haven Harbor, (Fig. 62), has been improved by the construction of breakwaters at the entrance, and by dredging a channel with a minimum width of 400 feet and depth of 20 feet to Tomlinson Bridge. The depths at the principal wharves range from 12 to 18 feet. The average velocity of the current at strength is 1.2 knots. The mean rise and fall of tide is 6 feet.

West River, between New Haven and West Haven, (Fig. 62), has been dredged to a minimum width of 100 feet and a depth of 12 feet.

The test board on the Housatonic River is located on the New York, New Haven & Hartford Railroad bridge, about 2½ miles above Milford Point, (Fig. 62). The river has been dredged to a depth of 7 feet and a width of

100 feet. The average velocity of the current on flood is 1.3 and on ebb 1.6 knots with a mean rise and fall of tide of 6.5 feet. The river above Stratford is closed by ice during the winter, which occasionally extends to the entrance in severe winters.

Bridgeport Harbor, (Fig. 63), has been improved by the construction of two converging breakwaters at the entrance and by dredging a straight channel 300 feet wide and 22 feet deep from the entrance to the anchorage basin, and 18 feet deep in the harbor and Poquonock River. The depths alongside the railroad wharf and the City Dock are 18 to 20 feet and at some of the wharves in Poquonock River there are depths of 10 to 13 feet. The average current velocity at strength is 0.7 knots with a mean rise and fall of tide of 6.5 feet.

On the Saugatuck River, or Westport Harbor, the test board is located on the New York, New Haven & Hartford Railroad bridge at Saugatuck, about 2½ miles above the entrance (Fig. 63). The depths at the principal wharves are 8 to 10 feet. The mean rise and fall of tide is 7 feet.

Norwalk River has been improved by dredging a channel 150 feet wide and 10 feet deep to South Norwalk, (Fig. 63), where the test board is located at the crossing of the N. Y., N. H. & H. R. R. The mean rise and fall of tide at this point is 6.5 feet.

Marine Borers

Past History—The records of the Corps of Engineers U. S. A. show that *Limnoria* is present throughout all this territory and the life of unprotected timber is estimated to be from 10 to 15 years. The New York, New Haven & Hartford Railroad reports past attacks on their structures as follows:

Allyns Point	Coal Dock of untreated timber.	Light attack of *Limnoria* prior to 1918. Dock first built in 1870. Age of present piling, 19 years. Condition, good.
New London (Shaws Cove)	Pile trestle, 384 chestnut and 40 oak piles—untreated.	Light *Limnoria* attack prior to 1908
New London	New England Steamboat Pier. 800 chestnut and 160 oak piles—untreated.	Light *Limnoria* attack prior to 1909
Guilford	East River Bridge. Pile trestle—untreated.	Heavy *Limnoria* attack. Condition of piles in 1921 such that replacement of piles driven in 1905 was necessary.
New Haven	Water Dock on untreated chestnut piles.	Slight *Limnoria* attack on old piles. Replacement piles driven in 1918 are undamaged.
New Haven	Belle Dock on untreated chestnut piles.	Majority of piles in place since 1885. Very slight *Limnoria* attack.
New Haven	Shop Dock on untreated chestnut piles.	Original piles driven in 1891 somewhat affected by *Limnoria*. Replacement piles driven in 1915 undamaged.
New Haven	Canal Dock on untreated chestnut piles.	Built in 1887. Majority of original piles somewhat affected by *Limnoria* action. Replacement piles driven in 1920 are undamaged.
New Haven	Heaton's Wharf on untreated chestnut piles.	Built in 1885-6. Some damage by *Limnoria* in past.

New Haven	Digger Dock on untreated chestnut piles.	Built about 1887-88. Extended in 1907 and 1910. Original piling shows traces of *Limnoria* action. 1907 and 1910 piles undamaged.
New Haven	Middle Dock on untreated chestnut piles.	Built about 1886-1887. Piles somewhat eaten by *Limnoria* and decayed.
New Haven	West River trestle—untreated chestnut piles.	Built in 1885. Renewed in 1909 due to poor condition on account of wood borers. 1909 piles slightly attacked. *Limnoria*.

Committee Investigations—Test boards were installed as follows:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Fishers Island, Fort Wright Q. M. Dock	4	Army	July 2, 1922	1.0	9.0
Mystic (Mystic River) Bridge No. 912	NH-5	N.Y.N.H. & H.R.R.	June 1, 1922	0.0	7.3
New London (Shaws Cove) Bridge No. 50.41	NH-4	N.Y.N.H. & H.R.R	June 1, 1922	0.0	10.2
New London (Central Coal Co. Pocket)	5	Army	June 3, 1922	1.0	13.0
New London (Submarine Base)	112	Navy	June 1, 1923	1.0	Pier A 18.0 Pier E 21.5 Pier G 15.5 Pier K 7.5
Allyns Point (Thames River), N. Y. N. H. & H. R. R. Coaling Wharf	NH-6	N.Y.N.H. & H.R.R.	June 1, 1922	0.0	4.5
Plum Island, Fort Terry Wharf	3	Army	July 2, 1922	1.0	12.0
Greenport, Texas Oil Co., Dock	2	Army	July 2, 1922	1.0	13.0
Guilford (West River) Bridge No. 16-19	NH-15	N.Y.N.H. & H.R.R.	June 1, 1922	0.0	9.5
New Haven (Digger Dock)	NH-16	N.Y.N.H. & H.R.R.	June 5, 1922	0.0	4.0
New Haven (Bell Dock)	6	Army	July 4, 1922	0.0	1.0
New Haven (West River) Bridge No. 59.32	NH-17	N.Y.N.H. & H.R.R.	June 5, 1922	0.0	5.3
Devon (Housatonic River)	NH-11	N.Y.N.H. & H.R.R.	June 1, 1922	0.6	10.0
Bridgeport (Poquonock River)	NH-12	N.Y.N.H. & H.R.R.	June 1, 1922	0.7	15.0
Westport (Saugatuck River)	NH-14	N.Y.N.H. & H.R.R.	June 1, 1922	0.2	7.0
South Norwalk (Norwalk River)	NH-13	N.Y.N.H. & H.R.R.	June 1, 1922	0.5	6.5
Davids Island (Fort Slocum) Q. M. Wharf	8	Army	May 18, 1923	1.0	13.0

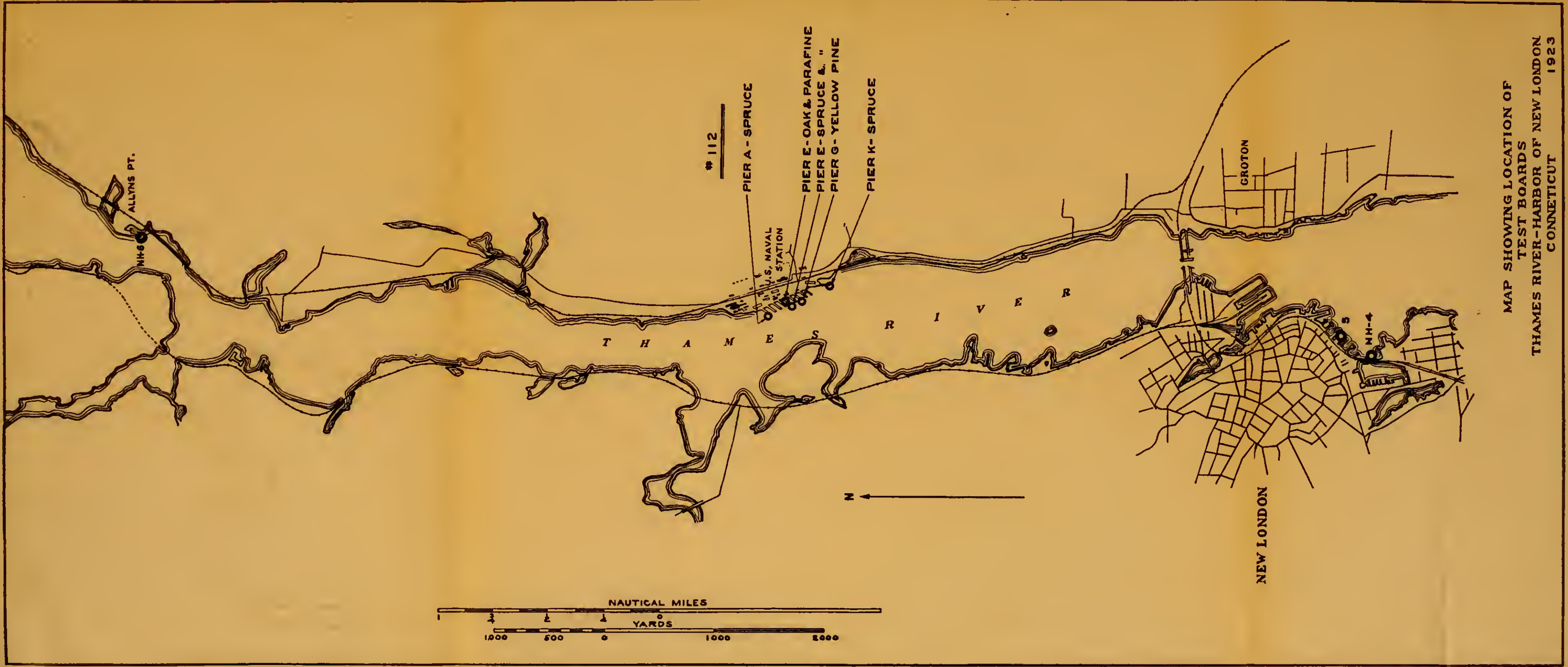
The result of inspection of the test blocks and specimens from these locations is as follows:

No. 4—This board showed a few specimens of *Limnoria* accompanied by Bryozoa in the first two blocks and on the third a *Teredo* larva was found. The board was lost and replaced November 11, 1922. Bryozoa and Algae appeared in January and the first *Limnoria* on March 1, and by May 15, about 60 specimens of *Limnoria* had appeared. The board was again lost.

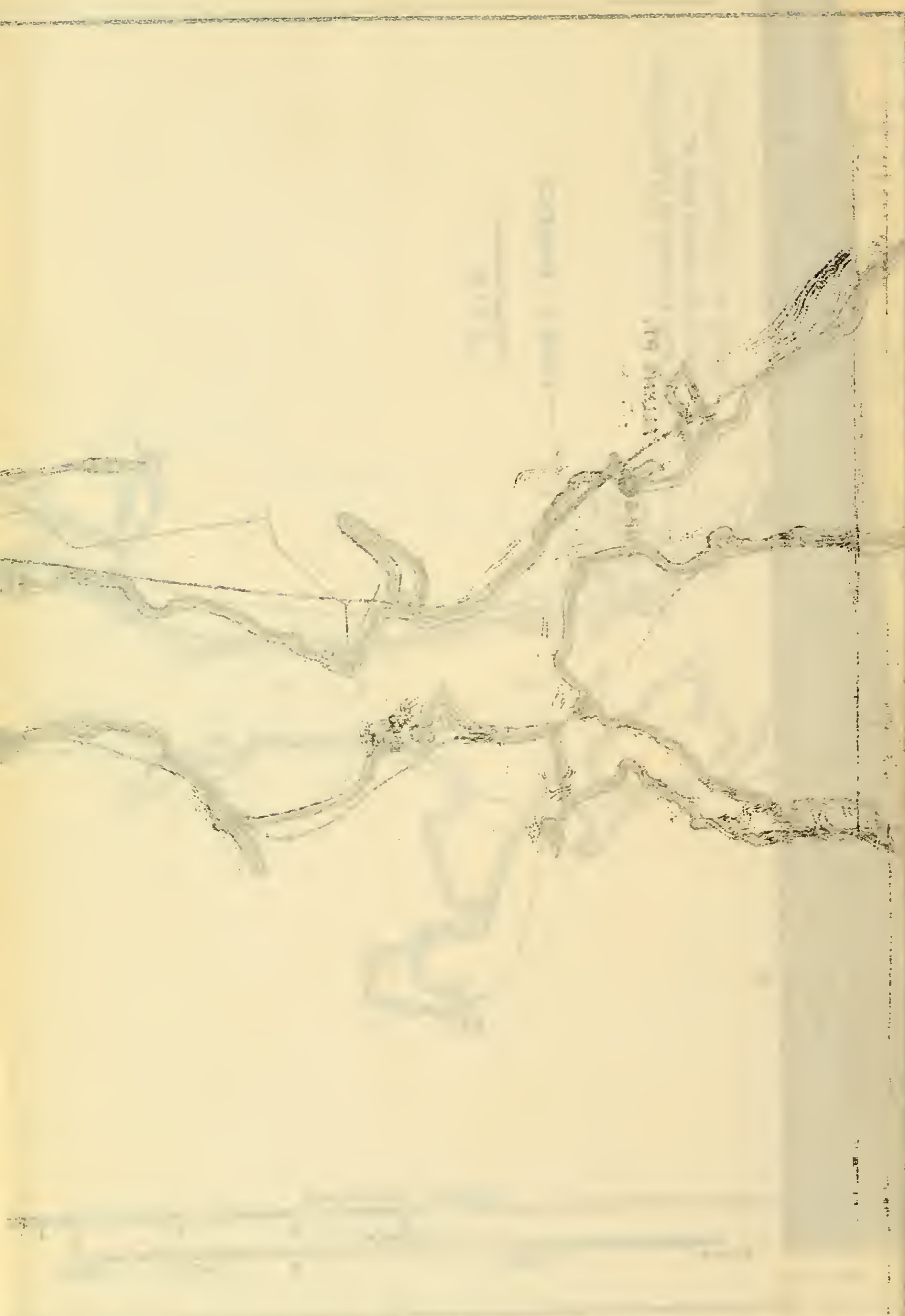
Specimens of cedar and spruce slats from lobster pots collected in the summer of 1923 were filled with *Teredo navalis*.

NH-5—*Limnoria* appeared on the second block, numerous *Teredo* larvæ on block 5, removed August 15 and in block 8, removed October 16, there was a large number of *Teredo navalis* two to four inches in length. The blocks were thoroughly honeycombed and a new board was placed April 15, 1923, but *Teredo navalis* did not appear until the blocks removed September 16, when a few from one-sixteenth to one-eighth-inch long were found. This number had slightly increased on October 15. Associated organisms were *Balanus*, Bryozoa (*Bugula*), Ostracoda and *Molgula*.

FIG. 61



MAP SHOWING LOCATION OF
TEST BOARDS
THAMES RIVER-HARBOR OF NEW LONDON
CONNETICUT
1923
#112
PIER A - SPRUCE
PIER E - OAK & PARAFINE
PIER E - SPRUCE & "
PIER G - YELLOW PINE
PIER K - SPRUCE
U.S. NAVAL STATION
ALLYNS PT.
NH-6
GROTON
THAMES RIVER
NH-4
5
NEW LONDON
N
NAUTICAL MILES
YARDS
1000
500
0
1000
2000




NEW HAVEN
6
NH-16
NH-17
GUILFORD
NH-15
STRATFORD
NH-11
LONG ISLAND SOUND
EASTERN PORTION
3
PLUM I.
N
MAP SHOWING LOCATION OF
TEST BOARDS
LONG ISLAND SOUND
NAUTICAL MILES
1 2 3 4 5 6 7
YARDS
1000 0 5000 10000
2
GREENPORT
GREENPORT HBR.
SAG HARBOR
PORT JEFFERSON
LONG ISLAND

FIG. 63


WESTPORT
STAMFORD
SOUTH NORWALK
NH-13
NH-14
BRIDGEPORT
NH-12
NEW ROCHELLE
8
LONG ISLAND SOUND
WESTERN PORTION
N
FORT SCHUYLER
14
15
FT. TOTTEN
PORT WASHINGTON
OYSTER BAY
MAP SHOWING LOCATION OF
TEST BOARDS
LONG ISLAND SOUND 1923
NAUTICAL MILES
YARDS

NH-4—The first *Teredo navalis* about ⅛ inch long appeared in the block removed September 16, and the number increased to about 20 per block from 2½ inches to 3 inches long before January 1, 1923. Larvæ first appeared in the gills in June, 1923, and the longest animal found up to September 16 was 5 inches. The first animals of the 1923 brood appeared on the block removed October 1. *Limnoria* attack was severe; the associated organisms were *Balanus*, Bryozoa, Red Algae and Foraminifera. A large sewer discharges near this board.

No. 5—*Limnoria* appeared in the first block and *Teredo navalis* one-fourth to one-half inch long in the fourth, removed September 15; larger numbers about 3 inches long were found in all blocks up to No. 20, removed May 15, when a new board was placed. No specimens of *Teredo* appeared in this new board before October 1, but the *Limnoria* attack was very heavy. Associated organisms were *Balanus*, Bryozoa, Red Algae, Mytilus and Gasteropods.

No. 112—The finger piers A to K were built on unprotected piles and the *Teredo* attack on the piles was found to be quite variable. Therefore boards were placed on four piers to endeavor to get information as to variation in the attack. The attack in 1923 was very light, since *Teredo navalis* was not found until the blocks removed October 1, and then in very small numbers. The *Limnoria* attack was also light. Associated organisms were *Balanus*, Bryozoa, Mytilus and Tubularia. Fig. 64 shows the condition of untreated pine piling after 5 years' service.

NH-6—Aside from two specimens of *Limnoria* on one block no borers were found. Associated organisms were *Balanus*, Green Algae and a few Bryozoa and Mytilus.

No. 3—A few specimens of *Limnoria* associated with *Balanus*, Bryozoa, Mytilus and Green Algae were found on the original board, which was replaced by a new board on May 19, 1923. No change occurred during the summer of 1923.

No. 2—Two boards were placed and lost after short periods of immersion. *Limnoria* associated with Bryozoa (*Bugula*) were found in the few blocks received.

NH-15—The first *Teredo*, ⅛ inch long, was found in the block removed September 11, 1922. Lengths of from two to four inches were attained before November 1 after which growth ceased. From 8 to 15 animals were found in each block. Associated organisms were *Balanus* and a few Bryozoa. *Limnoria* was much more destructive in 1923 than in 1922.

NH-16—*Limnoria* was fairly destructive and no associated organisms other than Green Algae were found.

No. 6—This board was only in service until February 16, 1923, and showed no marine organisms except slight traces of Green Algae.

NH-17—A few specimens of *Limnoria* associated with a small number of *Balanus* were the only organisms found on this board.

NH-11—A few Bryozoa were the only organisms found at this station.

NH-12—One block out of 33 showed a few specimens of *Mytilus* and Bryozoa; the others showed no life.

NH-14—*Limnoria* first appeared July 1, 1922, and *Teredo navalis* about September 1. All later blocks showed from 10 to 35 specimens of *Teredo*. Associated organisms were *Balanus*, Bryozoa and a very few specimens of *Mytilus* and *Petricola*.

NH-13—The first specimens of *Teredo navalis* appeared about September 1, 1922, and they reached a length of 3 to 4 inches by the close of the season with about 20 animals in each block. A new board was immersed April 15, 1923, and the first *Teredo* appeared between September 1 and September 15. Associated organisms were *Balanus,* Bryozoa and a few specimens of *Mytilus.*

A pile dolphin built with unprotected piles, driven in 1919 at White Rock, had to be removed in September, 1922, on account of damage by *Teredo navalis.*

No. 8—This board only remained in service for six weeks and did not in that time show any borers, although a number of specimens of *Balanus* were found. A rather heavy attack by *Teredo navalis* was found in timber removed from the wharf.

Special Tests

In order to determine whether there was any difference in the intensity of attack or any difference in the boring shells in different kinds of timber, specimens of pine, spruce and oak were immersed at the Submarine Base, New London, on May 1, 1922. When examined one year later the shells showed no differences, but the attack on the pine and spruce was very heavy, while it was only of medium intensity on the oak. This result was the opposite of that obtained at Galveston.

Methods of Protection

It has not been the custom to protect timber against the attack of marine borers in this territory. Some creosote impregnation has been used in New Haven Harbor, proving effective against *Limnoria* action. Creosoted piles were used for the foundation of the quay wall and crane of the Submarine Base, New London, but sufficient time has not elapsed to determine the efficacy of the treatment.

Substitutes for Timber

Concrete—The Bureau of Yards and Docks reports on concrete work as follows:

> "The only concrete in Waterfront Structures at the New London Submarine Base is the mass Quay Wall and the foundation for the 30-ton crane at the end of Dock 'B.'
>
> "Quay Wall, 1: 2: 4 concrete cast in blocks 30 feet long and of depth and thickness indicated at various points.
>
> "Foundation under crane, 1: 2: 4 concrete partly mass and partly reinforced.
>
> "Concrete of Quay Wall subject to tide and wave action.
>
> "So far as can be noted all concrete is in excellent condition after four years' service."

The New York, New Haven & Hartford Railroad Co. reports that it has several concrete structures in this territory and that, as a whole, little trouble has been experienced with them. In addition the following statement is made: "At a few locations, particularly Cos Cob, Bridgeport and New Haven, six to ten inches of the face of some of the concrete structures within tide limits deteriorated quite badly within three to five years. We believe this is due to a poor lean mixture of the original concrete. These particularly bad places have been repaired by taking off the poor materials and facing up with a new rich mixture of concrete either in form work or

by use of the cement gun. Some of this work was done five or six years ago and there has been no resulting deterioration since."

Conclusions

Teredo was not found at Allyns Point (NH-6), Fort Terry (3), Greenport (2), Digger Dock (NH-16), Bell Dock (6), West River (NH-17), Devon (NH-11), and Bridgeport (NH-12), but there is good reason to think that it is present at some of these locations, such as Greenport. *Limnoria* in large numbers was found at the Digger Dock and in small numbers at the other locations except at Bell Dock (6), Devon Hill (NH-11), and Bridgeport (NH-12). These three latter locations, therefore, appear to be the only ones at which protection for piles is not economically desirable for the prevention of damage by borers.

At some of these locations where *Limnoria* is present only in small numbers it is probable that protection would be economical only for important structures when the cost of replacement would be high either on account of the character of the structure or the resulting interference with traffic.

Pile protection would be an economy at all other locations.

The attack of *Teredo navalis* seems to have been lighter and to have commenced from two weeks to a month later in 1923 than in 1922. It appears probable that the period of inactivity and consequently of immunity from attack ordinarily extends from about September 15 to July 15.

NEW YORK HARBOR

For purposes of this report, New York Harbor, (Fig. 65), is considered to be the waters of the Hudson, Harlem and East Rivers, the Upper and Lower Bays, the Kill van Kull, Arthur Kill, Newark Bay, Raritan and Jamaica Bays —all between Willets Point, Sandy Hook, Coney Island, and the north end of Manhattan Island. The report also includes for convenience certain data collected on the south shore of Long Island.

Marine Borers

Past History—The earliest evidence of the presence of marine borers in New York consists of specimens of *Teredo navalis* found many years ago in the wreck of a British frigate sunk in Hell Gate during the Revolutionary War. These specimens may be found in the Academy of Natural Sciences, Philadelphia. Prior to 1870 reports indicate that marine borers were active and destructive throughout the harbor, that by 1875 their activities had considerably lessened and that, except for localized sporadic outbreaks, they have done little damage in the rivers since that time. In 1898 a wharf at Greenpoint failed on account of the attack of teredine borers, but other structures in the immediate vicinity were not seriously damaged. It has been thought that the long continued high degree of pollution has probably been responsible for the immunity which has appeared to exist.

In 1922 the "New York Committee," organized to cooperate with the National Committee, sent out an exhaustive questionnaire to wharf owners in the harbor as defined above, and also to owners on the New Jersey coast as far south as Atlantic City, and to those in Long Island Sound. These questionnaires were intended to collect as complete a record as possible of the history of borer attacks in the territory under investigation, and also to ascertain whether any indications had appeared of heavier attack in the last few years.

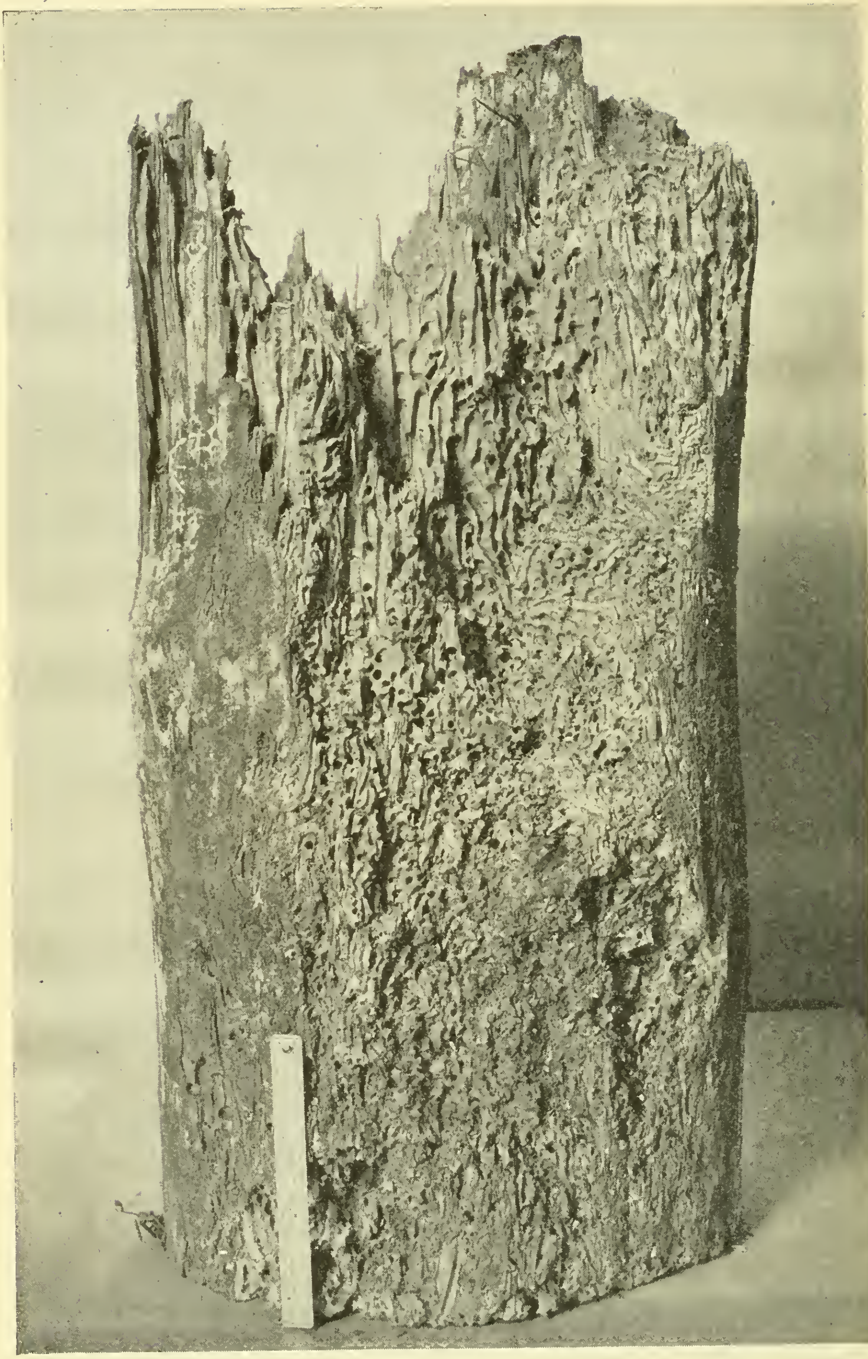


FIG. 64—UNTREATED PINE PILE, U. S. N. SUBMARINE BASE, NEW LONDON, CONN.
Driven, 1918—Removed, 1923.

Approximately 1,100 questionnaires were sent to owners in the entire district. Separate reports are being made for Long Island Sound and the New Jersey Coast south of Sandy Hook, and deducting the replies received by the New York Committee from these two areas, reports received covered 292 structures in the New York Harbor area. Two hundred twenty-nine of these reports showed no recorded attack, 22 gave a record of past attacks, and 41 reported present attacks.

The 22 structures from which past attacks were reported, where no attack was thought by the owners of the structures to be going on at present, were located as follows:

Pier 35 East River, Jefferson St., Manhattan	Attack in 1916
Port Morris, East River	Attack in 1914
Greenpoint, East River structure collapsed	Attack in 1898
Edgemere (Rockaway Point) and Barren Island	Attack in 1894-97
Weehawken, N. J.-Erie R. R. Piers	Attack in 1908
Weehawken, N. J.-N. Y. C. R. R. Piers	Attack in 1911
Weehawken, N. J.-N. Y. C. R. R. Piers	Attack in 1922
Pier 16—Hudson River at Barclay St., Manhattan	Attack in 1909
Pier 1—Hudson River at 70th St., Manhattan	Attack in 1909
Hoboken, N. J., Public Service Ry. Co	Attack in 1906
Communipaw, N. J	Attack in 1898
Perth Amboy, N. J.	
Port Richmond, Staten Island, Kill van Kull.	

Except for the attacks at Greenpoint and Edgemere no very extensive damage was reported at any of these locations. While a few specimens of *Limnoria* have been found, such damage as occurred has generally been caused by *Teredo navalis*.

The reports of present attack are generally based on the inspection of timber removed from the water between the years 1919 and 1922.

These reports are as follows:

East River between the Battery and Fort Totten has six reports of present attack by teredine borers, all light.

The Hudson River from the Battery to Tarrytown shows seven points of attack, all light and all below Edgewater.

The Upper Bay between the Narrows, the Battery and Communipaw showed twelve locations where there was thought to be attacks, most of them on the Staten Island shore.

The Kill van Kull, Arthur Kill, Newark Bay and tributaries, reported sixteen locations, most of them on the Kill van Kull, where the attack was of medium intensity.

The Lower Bay reported one location only, which merely indicates that many owners did not reply.

The south shore of Long Island reported very heavy attacks in seven locations.

Committee Investigations—The New York Committee was organized in March, 1922, and the investigations were made under the general direction of that committee. The Director of the National Committee acted as the executive for the New York Committee as well as for the National Committee, and employed for work exclusively in the New York district an engineer, a biologist and a chemist for various periods.

The New York Committee placed a number of test timbers in the harbor early in 1922, and later installed standard test boards at many of the same locations. It was difficult to keep test boards in service, as many were lost, probably by theft. In addition to the collection of specimens by the test board method, arrangements were made with a number of wharf owners and with contractors for notice of repairs which involve the pulling of piles so that an inspection of such timber could be made by the biologist employed by the committee. The test boards, manufactured by the New York Central Railroad, were located as follows:

SECTION 1, EAST RIVER—BATTERY TO WILLETS POINT—AND HARLEM RIVER

BOARD NO.	LOCATION	MAINTAINING AGENCY	DATE INSTALLED
15	Fort Totten	Army	
14	Ft. Schuyler	Army	
13	Rikers Island	Army	July 5, 1922
89	Willis Ave.	N. Y., N. H. & H. R. R.	June 1, 1922
57	Wards Island	N. Y. Dept. of Docks	Aug. 2, 1922
53	Grand St. Pier	N. Y. Dept. of Docks	Aug. 2, 1922
93	Pier 35, East River	N. Y. C. R. R.	June 15, 1922
95	Pier 4, East River	N. Y. C. R. R.	Aug. 29, 1922
111	S. 3rd St., Brooklyn	Am. Sugar Ref. Co.	March 1, 1923
31	Pier C, Navy Yard	Navy	July 27, 1922

SECTION II—HUDSON RIVER

60	West 156th St.	N. Y. Dept. of Docks	Aug. 2, 1922
59	West 52nd St. Pier	N. Y. Dept. of Docks	Aug. 2, 1922
28	Barrow St. Rec. Pier	N. Y. Dept. of Docks	Aug. 1, 1922
94	Weehawken, N. J.	N. Y. C. R. R.	May 1, 1922
94L	Weehawken, N. J.	N. Y. C. R. R.	June 1, 1922
102	Hoboken, N. J.	D., L. & W. R. R.	Aug. 1, 1922
107	Eagle Works, Jersey City	Standard Oil Co.	Nov. 1, 1922
103	Pier A, Jersey City	Lehigh Valley R. R.	Sept. 22, 1922
96	Pier 22	B. & O. R. R.	Aug. 1, 1922
51	The Battery	N. Y. Dept. of Docks	July 27, 1922

SECTION III—UPPER BAY—KILL VAN KULL—ARTHUR KILL, NEWARK BAY

41	35th St. Pier, Gowanus Bay	Navy	July 14, 1922
42	Bay Ridge Barracks, Brooklyn	Navy	July 25, 1922
43	Ft. La Fayette	Navy	July 18, 1922
64	Pier 18, Clifton, S. I.	N. Y. Dept. of Docks	July 27, 1922
104	Tompkinsville Lighthouse, S. I.	Bureau of Lighthouses	Oct. 11, 1922
63	Pier 6, Tompkinsville, S. I.	N. Y. Dept. of Docks	July 27, 1922
98	St. George, S. I.	B. & O. R. R.	Aug. 1, 1922
48	Constable Hook	Navy	Oct. 6, 1922
106	Bayonne	Standard Oil Co.	Nov. 1, 1922
110	Warner, N. J.	Am. Cyanamid Co.	Feb. 15, 1923
100	Elizabethport, N. J.	Singer Mfg. Co.	July 15, 1922
108	Bayway, N. J	Standard Oil Co.	Nov. 1, 1922
47	Rossville, S. I.	N. Y. Dept. of Docks	Aug. 11, 1922
21	Newark Bay Ridge	C. R. R. of N. J.	July 17, 1922

SECTION IV—LOWER BAY, JAMAICA, GREAT SOUTH BAY AND RARITAN BAY

65	Midland Beach Pier, S. I.	N. Y. Dept. of Docks	Aug., 1922
66	Princess Bay	N. Y. Dept. of Docks	Aug. 11, 1922
95	Perth Amboy, N. J.	B. & O. R. R.	Aug. 1, 1922
22	Perth Amboy, N. J.	Army	July, 1922
99	Tottenville	B. & O. R. R.	Aug. 1, 1922
24	Atlantic Highlands, N. J.	Army	July, 1922
23	Ft. Hancock, Sandy Hook	Army	July 29, 1922
44	Marine Basin, Gravesend Bay	Navy	July 18, 1922
68	Atlantic Y. C. Pier, Sea Gate	N. Y. Dept. of Docks	July 20, 1922
69	Steeplechase Pier, Coney Island	N. Y. Dept. of Docks	July 20, 1922
45	Manhattan Beach, Coney Island	N. Y. Dept. of Docks	Aug. 9, 1922
70	Barren Island, Jamaica Bay	N. Y. Dept. of Docks	Aug. 1, 1922
71	Mill Basin, Jamaica Bay	N. Y. Dept. of Docks	Aug. 8, 1922
73	Jamaica Bay R. R. Trestle	L. I. R. R.	Aug. 8, 1922
72	Jamaica Bay R. R. Trestle	L. I. R. R.	Aug. 8, 1922
30	Fire Island	Navy	Aug. 8, 1922
101	West Sayville, L. I.	Blue Points Co.	Aug. 1, 1922
109	Point O'Woods	Bay Shore Yacht Club	Nov. 20, 1922

The results of the inspection of test blocks and timber from structures are as follows:

SECTION I—No representatives of *Teredo* or *Limnoria* were found in test blocks in this section except that a few specimens of *Limnoria* were found at Rikers Island, but *Balanus* and Bryozoa were found at Rikers Island and Pier 4. The presence of these animals generally indicates that the water conditions are such that *Teredo* can live.

No life of any kind was found on the blocks from Willis Avenue in the Harlem River nor those from South Third Street, Brooklyn.

Live *Teredo navalis* was found in timber from Fort Slocum, Clason Point, Astoria, Ferry Slip 5 at South Street, and Ferry Slip 2 at Whitehall Street. The attack was fairly heavy at Fort Slocum and Clason Point, but only a few animals were found at the other locations. A comparatively light *Limnoria* attack was also found at the ferry slips near the battery.

Piles from structures at the foot of East 110th Street, East Thirty-seventh Street, East Twenty-eighth Street and Grand Street showed evidence of having been attacked in the distant past, but none showed recent attack.

It would seem to be indicated that a serious attack need not be expected in the Harlem River, since no encrusting or boring organisms have been found there; that a destructive attack can apparently occur near the entrance to Long Island Sound, but that in the remainder of the East River, while *Teredo* is present and can live, it does not seem to threaten a destructive attack at the present time. The number of points near the Battery at which *Teredo* has been found shows that this is a point where attack is a possibility, and therefore structures in this vicinity should be carefully watched.

SECTION II—No organisms were found on the blocks at West 156th Street, at the Barrow Street Pier, nor at the Eagle Works of the Standard Oil Company. *Balanus* and Bryozoa as well as Algae were found on the blocks at the Battery, Pier 22, North River, Hoboken, Weehawken and Pier A, Lehigh Valley at Jersey City, showing that in all probability *Teredo* can

live in these locations, and this is confirmed by the finding of a few live specimens of *Teredo* in piles from the Wilson Line Pier at Hoboken and a larger number at Pier A (Fig. 67), of the Lehigh Valley Railroad at Jersey City, as well as old borings in piles from the Christopher Street Ferry and at Edgewater. *Limnoria* has been found at the Battery, West Fifty-second Street and Pier 22, North River, but not in great numbers.

While no damage of importance has been done in this section recently, the finding of a few specimens of *Teredo* at Hoboken, and a larger number at Jersey City, shows that this area is at least suspicious and that frequent inspections should be made. In the Lehigh Valley piers, while the number of animals found was small, the fact that they were found in many of the piles examined, shows that the vicinity is one to be carefully watched.

SECTION III—The test blocks at most stations in this section, or timber taken from structures, show both *Teredo* and *Limnoria* to be widely distributed, except in the Arthur Kill and Newark Bay. The boards at the Thirty-fifth Street Pier, Gowanus Bay, Tompkinsville Lighthouse Pier, and Constable Hook, did not show *Teredo,* but did show *Balanus,* Bryozoa and Algae.

Limnoria made a rather light attack on the blocks at Bay Ridge Barracks, Gowanus Bay, and Pier 6, Tompkinsville, and a fairly heavy attack at Fort LaFayette.

Living specimens of *Teredo* were found at the following locations in either test blocks or in timber from structures:

Bay Ridge Barracks—Light attack.
Fort LaFayette—Light attack.
Tompkinsville Lighthouse Pier—Light attack.
Pier 18, Clifton—Moderate attack.
Pier 6, Tompkinsville—Moderate attack.
Baltimore & Ohio, Pier 2, St. George—Moderate attack.
New Brighton Pier—Light attack.
Babcock & Wilcox Pier, Bayonne—Light attack.

Pier 6, Standard Oil Company, Bayonne—Live specimens of *Teredo* were not found, but the borings were recent and some of the piles were practically destroyed by *Limnoria* and *Teredo* in five years, (Fig. 66).

The results of the survey in this section show that structures on Staten Island and in the Kill van Kull are subject to attack, and that *Teredo* is present in sufficient numbers to do very considerable damage. A slight local intensification of the attack might do serious damage in a short time. On the Long Island shore fewer numbers of *Teredo* were found, and structures on this side of the Upper Bay do not seem to be in as much danger, though they should be frequently inspected. Newark Bay and Arthur Kill do not seem to be in immediate danger of attack.

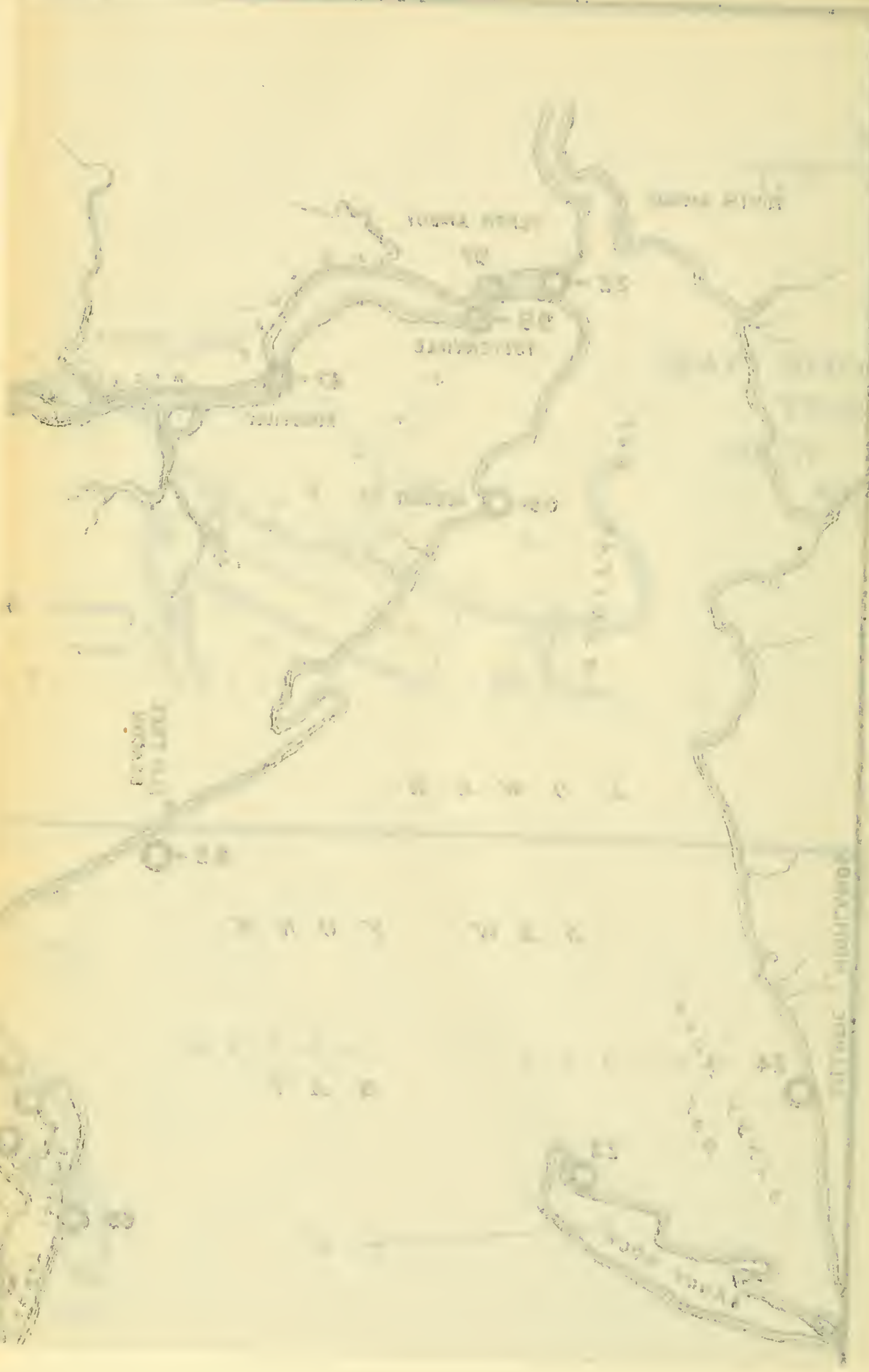
Near the Narrows, *Limnoria* is fairly destructive.

SECTION IV—All boards in this section showed *Balanus,* Bryozoa and Algae, indicating that the water conditions were probably suitable for *Teredo* and *Teredo* was found at practically all locations, either in the blocks or in timber removed from structures.

At Perth Amboy and the Marine Basin, Gravesend Bay, the attack was comparatively light. It was heavier at Barren Island, Mill Basin, Sandy Hook, and on the Long Island Railroad trestle in Jamaica Bay, and very

Fig. 65


MAP SHOWING LOCATION OF
TEST BOARDS
NEW YORK HARBOR
NEW YORK 1923
STATUTE MILES
SOUTH AMBOY
PERTH AMBOY
TOTTENVILLE
ROSSVILLE
ARTHUR KILL
ELIZABETHPORT
SEGUINE PT.
RARITAN BAY
STATEN ISLAND
NEWARK BAY
NEW
BAYONNE
PORT RICHMOND
CONSTABLE PT.
ELM TREE BEACON
STAPLETON
ST. GEORGE
CLIFTON
FORT WADSWORTH
LOWER
NEW YORK
BAY
UPPER
BAY
JERSEY CITY
HOBOKEN
WEHAWKEN
JERSEY
HUDSON
RIVER
MANHATTAN
EAST
RIVER
FORT HAMILTON
BAY RIDGE
BROOKLYN
CONEY ISLAND
LONG ISLAND CITY
ASTORIA
QUEENS
BRONX
BARETTO PT.
FLUSHING BAY
WESTCHESTER
EASTCHESTER BAY
WILLETS PT.
JAMAICA BAY
ROCKAWAY
ATLANTIC HIGHLANDS
SANDY HOOK BAY
SANDY HOOK
ATLANTIC OCEAN
N
22
97
99
47
66
21
106
48
104
63
64
65
42
43
103
96
102
51
28
95
94
59
41
93
31
53
111
60
57
89
68
44
24
23
69
45
71
70
13
14
15
73
72



heavy at Sea Gate, Steeplechase Pier, Manhattan Beach, Atlantic Highlands and Princess Bay.

Heavy *Teredo* attack was found both in blocks and timber at Fire Island and at West Sayville and Point O' Woods in Great South Bay. Five-inch diameter piles used for fish nets are destroyed generally by August of each year.

The attack by *Limnoria* was moderate in Gravesend Bay and heavy in the vicinity of Coney Island and Sheepshead Bay.

The activities of the borers cover practically this entire section, and except perhaps in the upper portion of Raritan Bay and in a small part of Gravesend Bay near the Marine Basin it would seem that protection of piles would be an economy, and that at some locations an unprotected structure may not be expected to last more than a few years. On account of the variation in intensity of attack from year to year which is shown by the records in many ports, it appears that a heavy and destructive attack may be expected in any part of this section at any time.

Period of Immunity—While results of the inspection of test blocks have shown larvæ landing on blocks as late as November, they do not seem to develop. It seems probable that no serious attack need be expected before July 1 and that growth generally stops in September. The period of practical immunity from attack, therefore, is between nine and ten months, September to July.

Water Analysis—Chemical analyses of the harbor water by determination of temperature, salinity, hydrogen-ion concentration and oxygen content were made at a number of points to find out what influence these conditions had on the activities of borers. A part of this work was done by the chemist of the Chief Engineer of the Board of Estimate and Apportionment of the City of New York. Analyses were also made by the Babcock & Wilcox Company at Bayonne, by the American Cyanamid Company at Warners, N. J., and the American Sugar Refining Company at Astoria. The Committee established seven stations on piers, some where *Teredo* had been found and some where it had not, and analyses were made by a chemist employed by the committee who worked under the general supervision of Dr. F. E. Hale of the Mt. Prospect Laboratory of the Department of Water Supply, Gas and Electricity of the City of New York. The results of these analyses are shown in Figs. 68 to 77 inclusive.

Currents—The movement of the currents in the rivers and Upper Bay is very complicated, and will be found discussed at length in the reports of the Metropolitan Sewerage Commission, in several papers in the Transactions of the American Society of Civil Engineers, and elsewhere.

There are ample currents at all points to aid in the distribution of the larvæ of *Teredo,* but the water does not pass freely through the Narrows and the entrance to Long Island Sound. There are reversals of direction which hold the water in the Upper Bay through several tidal cycles before it passes out. This action renders less likely the spread of infestation from the Lower Bay and Staten Island, where it exists, to other parts of the harbor than if the water flowed freely in and out with the tides.

This peculiar current action also tends to prevent the rapid evacuation of the pollution carried in the water and therefore concentrates this matter, allowing chemical and bacteriological action to take place. As has been demonstrated in other harbors, sewage pollution alone does not give im-

munity from borers, since the wooden outfalls of sewers have been frequently destroyed, and wharves under which sewers empty have been heavily attacked. There is evidence, especially in the case of New York, Baltimore, Havana and other ports, to show that a harbor in which the amount of pollution is high, the rate of evacuation low, and where this condition is continued over a period of years, that substantial immunity exists. That this condition of immunity will not continue after the removal of the causes of pollution and the lapse of sufficient time for the cleansing of the harbor waters is clearly shown in the case of Havana, Cuba.

FIG. 66—SECTION FROM A PILE DRIVEN IN STANDARD OIL PIER NO. 6. BAYONNE, N. J., IN 1915 AND REMOVED IN 1922.

Prior to the American occupation in 1898, this harbor was heavily polluted, and there were many very old timber structures in good condition. The installation of sewage disposal took away the sources of pollution, and after a few years the harbor purified itself, with the result that borers reappeared. As an example, the concrete steps in front of the Custom House may be cited. These steps were built by the United States Army Engineers on a foundation of old piles, which were sound after many years' service. A few years after the sources of pollution had been removed the steps failed on account of the destruction of the piles by borers.

The necessity of sewage disposal plants for the New York area is recog-

nized; some work of this kind has been done, and the construction of a comprehensive system in the not far distant future must be expected. After this is done the waters of the harbor will undoubtedly cleanse themselves, and considering the fact that the waters of Long Island Sound and of the nearby small harbors on the south shore of Long Island and the coast of New Jersey are heavily infested by *Teredo,* it seems certain that the attack in the Lower Bay may be expected to become much heavier and that the structures in the Upper Bay and in the rivers will probably no longer enjoy the comparative immunity which they now possess.

FIG. 67—SECTION OF PILE FROM LEHIGH VALLEY RAILROAD PIER A, JERSEY CITY FROM WHICH LIVE *Teredo Navalis* WERE EXTRACTED

Pile Protection

The City of New York contained 709 piers in 1920 (of which 267 were owned by the municipality), and there were probably at least 200 more on the New Jersey side. Of this great number of piers, in only very few cases are the piles protected from borers in any way, and so far as it has been possible to obtain records the only method of protection used has been that of impregnation with creosote.

Protected piles are not recorded on Manhattan Island except at Pier 9,

Hudson River (foot of Rector Street), where some creosoted piles were used under a steel shed by the Central Railroad of New Jersey about 1915. None are known on the New Jersey shore above Jersey City, excepting in Shipping Board Piers 1, 2, 3 and 4, at Hoboken, nor between Throgs Neck and the Navy Yard on the Long Island shore.

The coal piers of the Central Railroad of New Jersey at Communipaw were built in 1916 on creosoted piles, and the Lehigh Valley coal pier at Constable Hook was also built on creosoted piles at about the same time.

The Standard Oil Company of New Jersey have the following structures built wholly or in part with creosoted piles:

Pier 5, Bayonne—Built 1911-14—entirely creosoted piling.
Pier 6, Lower Hook—Built 1915-17—entirely creosoted piling.
Pier 4, Bayonne—Built 1897-98—12 outer bents creosoted piling.
Pier 1, Bayonne—Built 1897-98—A few bents creosoted piling.
Bulkhead—Pier 1 to Pier 5, Bayonne—built in 1918. This is a concrete bulkhead faced with 6-inch by 12-inch creosoted sheathing.
Bulkhead—Lower Hook Separator to west side of Pier 5, Lower Hook —built 1910-11.

In the last mentioned bulkhead the specifications provided for short leaf yellow pine piles treated with creosote with a penetration of not less than 1½ inches nor more than 2 inches, and in all other structures an impregnation of not less than 14 pounds per cubic foot was required. No specifications for the oil are available.

The concrete decked city pier at the foot of Canal Street, Stapleton, S. I., built about the same time, received the same treatment.

One of the oldest recorded structures built of creosoted piles is the series of three dikes built in 1874-75 by the U. S. Engineer Department in the channel between Staten Island and New Jersey. These piles received a treatment below 12 pounds per cubic foot and were reported to have been only slightly damaged by borers up to 1922.

The Richmond Light & Railroad pier at Rivington, built in 1893, with an addition in 1914, has creosoted piles.

The Army pier at Fort Tilden, Rockaway Point, built in 1917, is on piles treated with 14 pounds of creosote per cubic foot, and has been attacked by *Limnoria* at joints.

Substitutes for Timber

There are comparatively few concrete and almost no metallic structures in this harbor in proportion to the total number of structures.

The bulkheads built by the Municipal Dock Department at various times are generally concrete blocks of large size, air seasoned for a considerable period before being exposed to salt water. Various methods of construction conforming to what was considered good practice at the time was used. Generally these walls are reported to be in good condition.

There are a number of concrete structures at the Navy Yard built at various times and by various methods, and many of them have deteriorated seriously, both on account of chemical action and the action of ice.

Description of the construction methods and materials used in the various structures may be found in numerous papers in the Transactions of the American Society of Civil Engineers and other technical publications.

The Standard Oil Company has been using a considerable number of con-

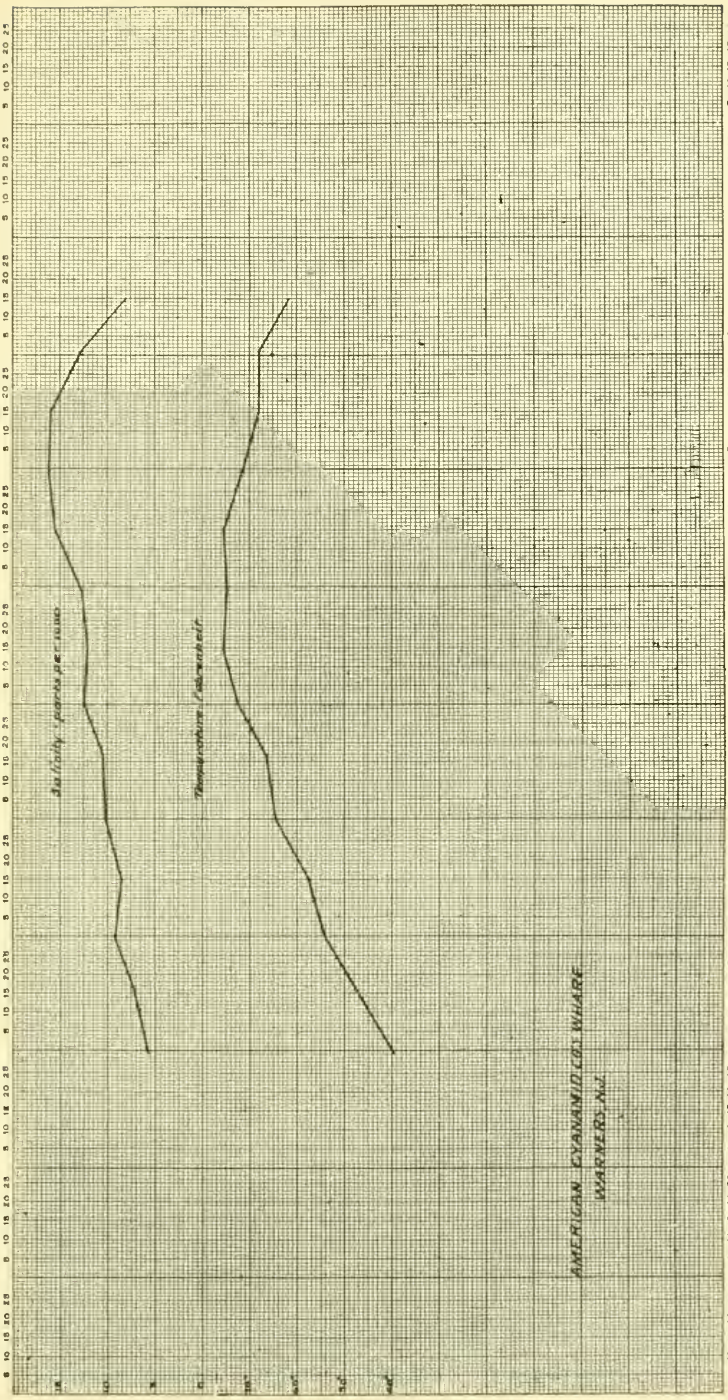


Fig. 68—Salinity and Temperature Observations, American Cyanamid Co.'s Wharf, Warners, N. J.

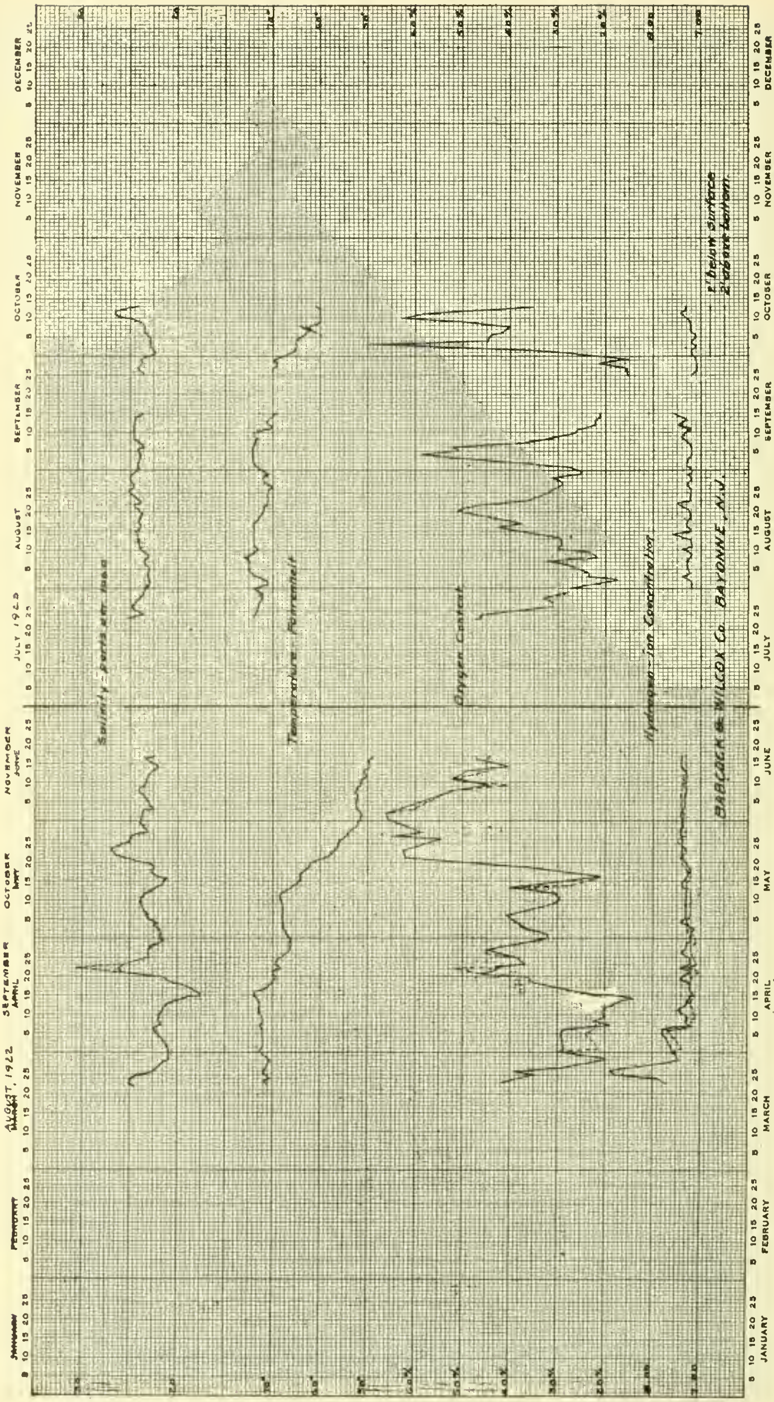


Fig. 69—Salinity, Temperature, Oxygen Content and Hydrogen-ion Concentration, Babcock and Wilcox Co.'s Pier, Bayonne, N. J.

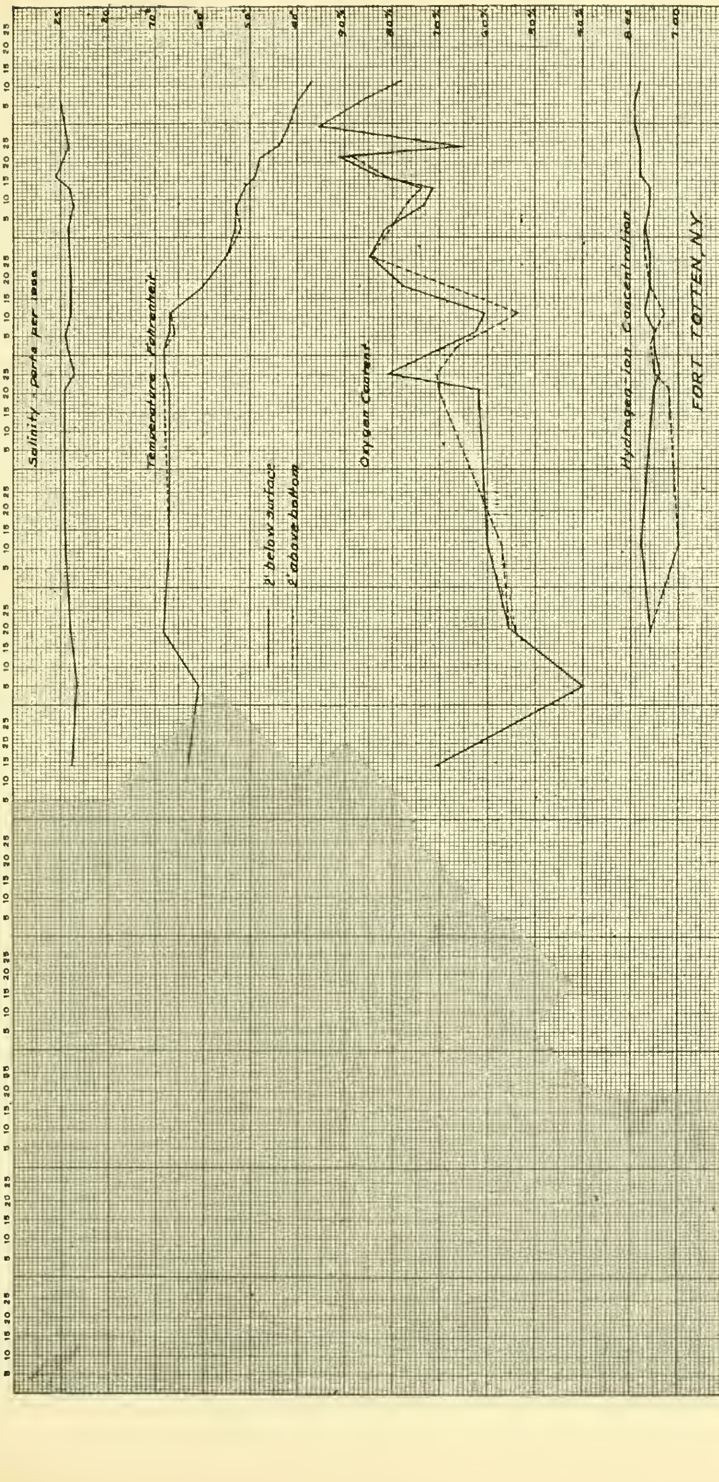


FIG. 70.—SALINITY, TEMPERATURE, OXYGEN CONTENT AND HYDROGEN-ION CONCENTRATION, FORT TOTTEN, N. Y.

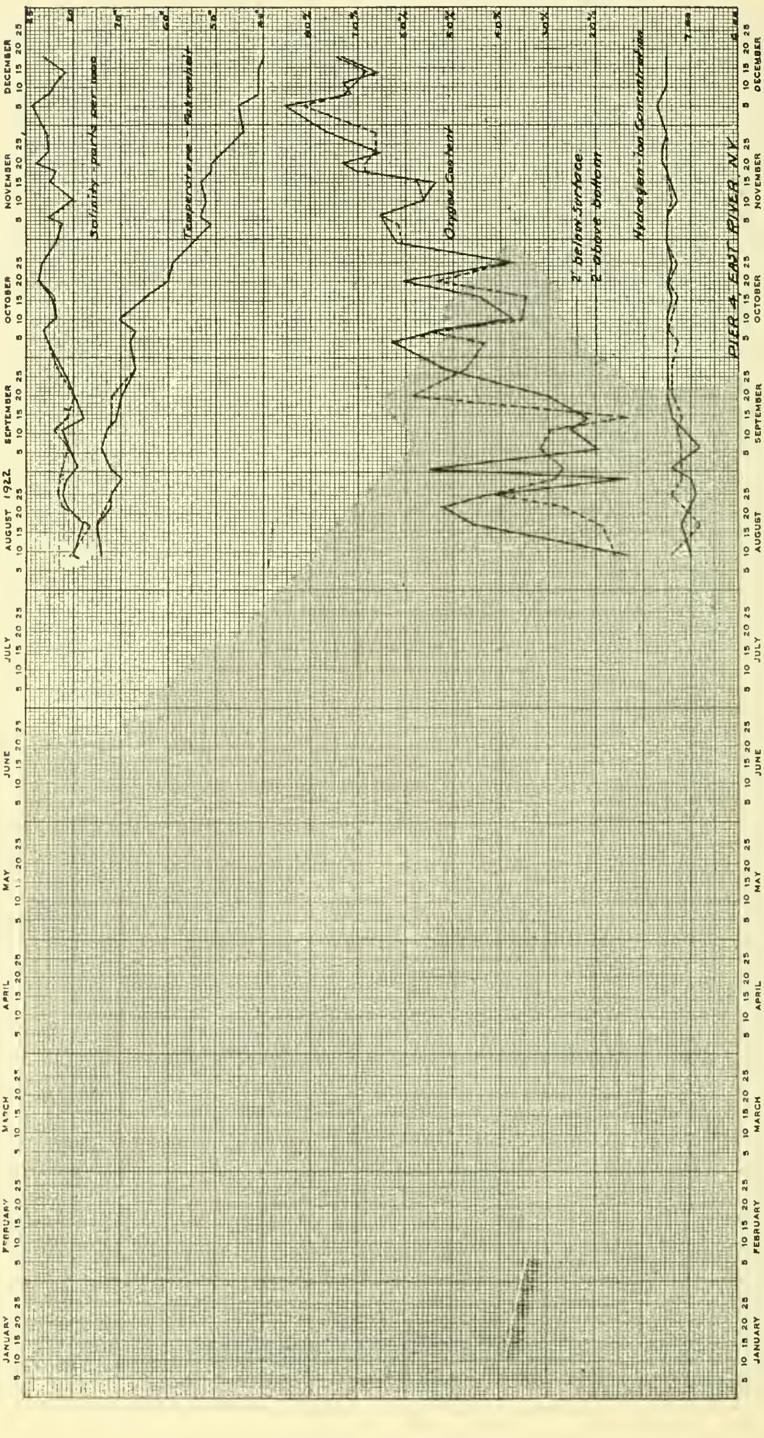


FIG. 71—SALINITY, TEMPERATURE, OXYGEN CONTENT AND HYDROGEN-ION CONCENTRATION, PIER 4, EAST RIVER, NEW YORK CITY

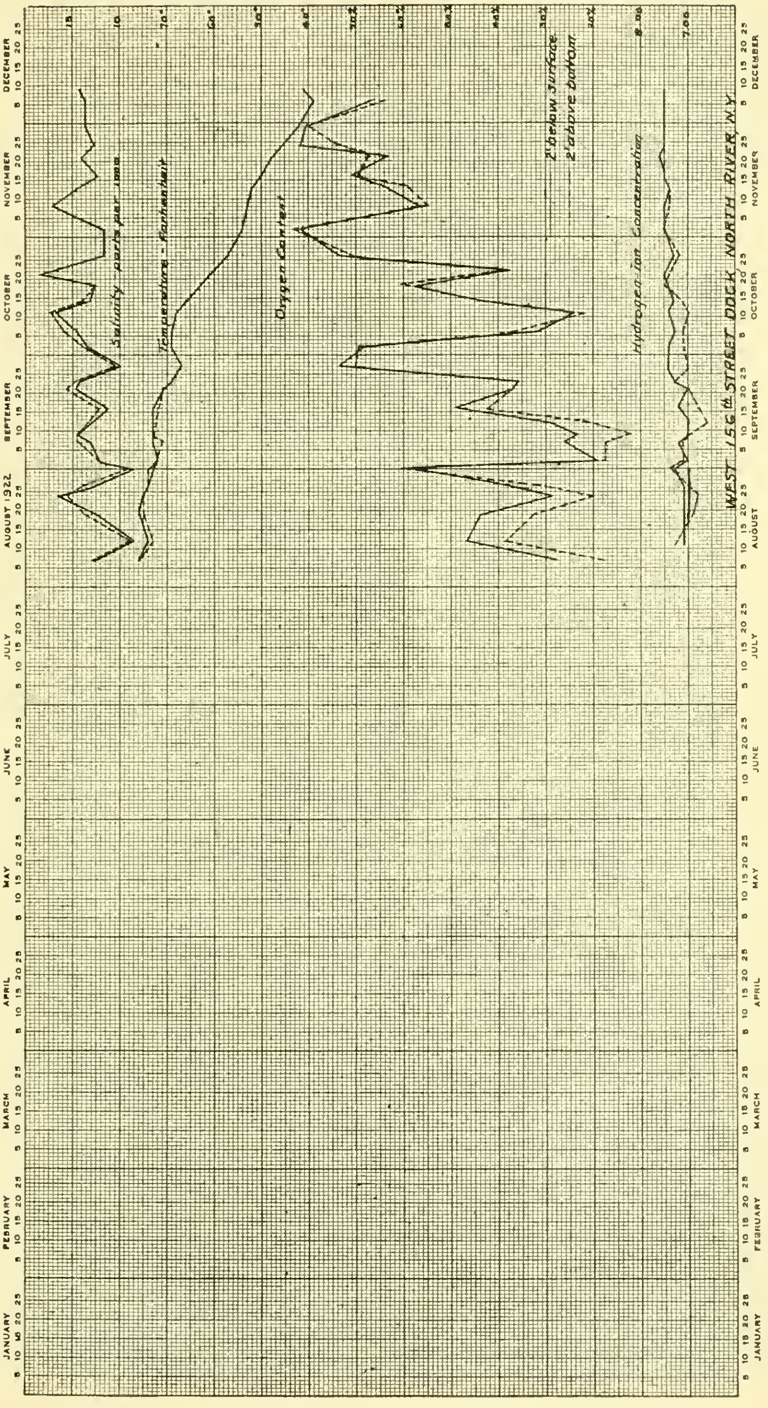


FIG. 72—SALINITY, TEMPERATURE, OXYGEN CONTENT AND HYDROGEN-ION CONCENTRATION, WEST 156TH STREET DOCK, NORTH RIVER, NEW YORK CITY

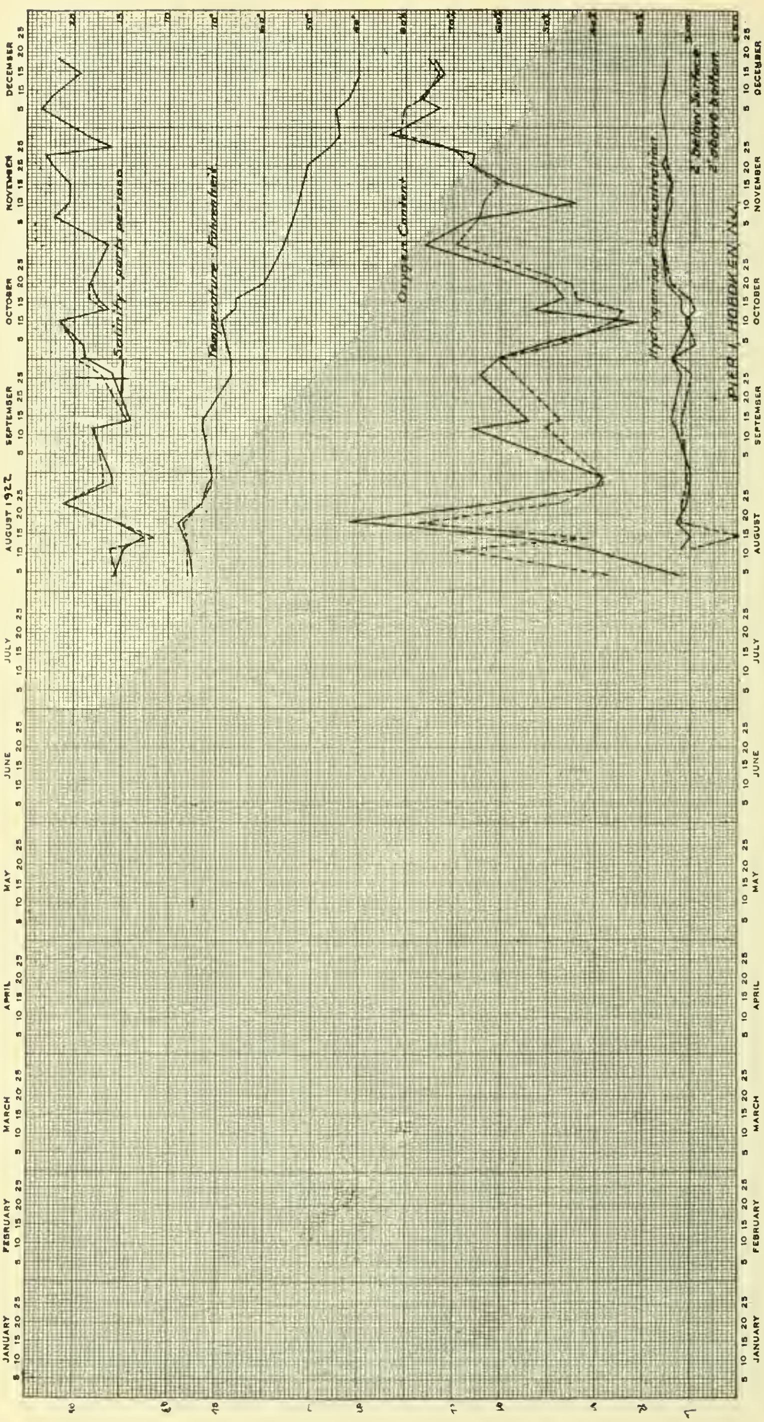


Fig. 73—Salinity, Temperature, Oxygen Content and Hydrogen-ion Concentration, Pier 1, Hoboken, N. J.

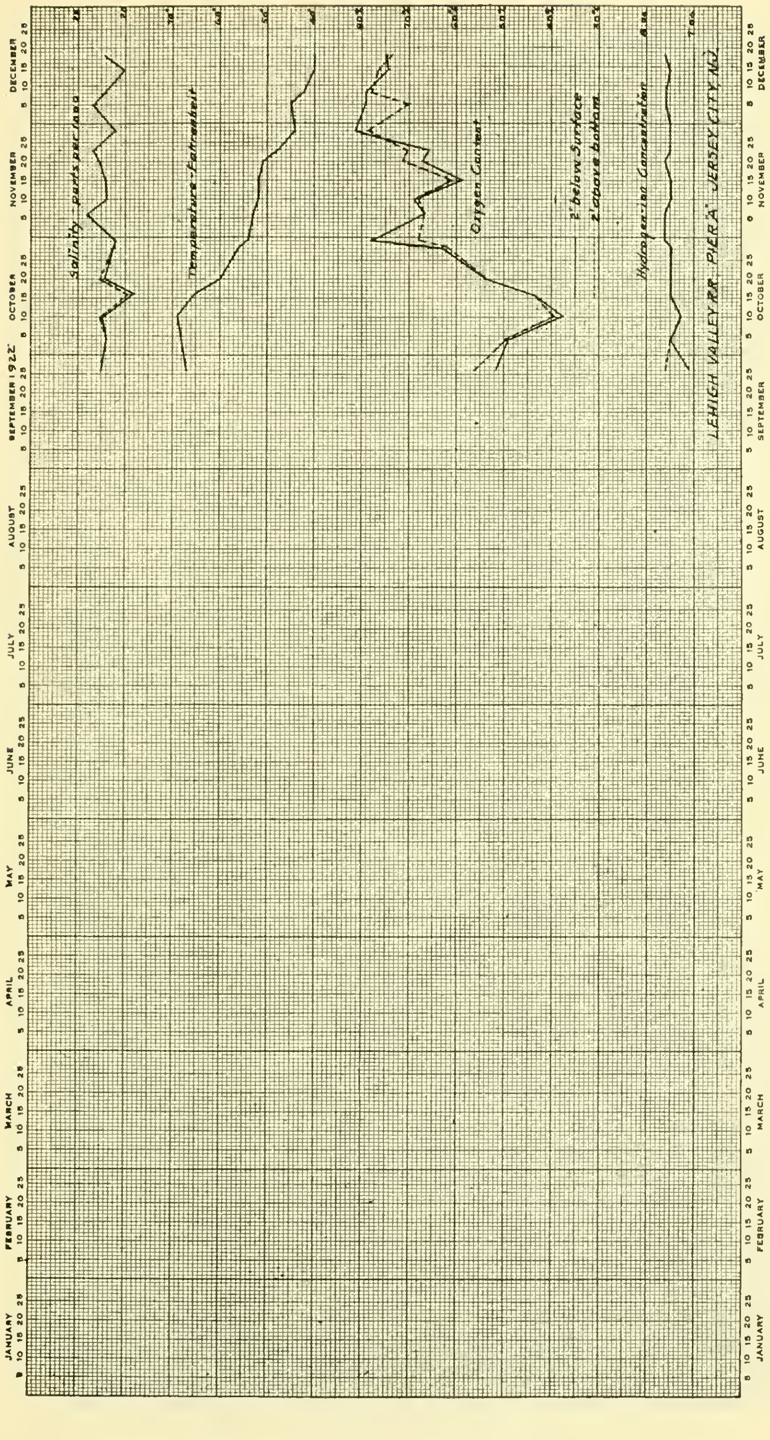


FIG. 74—SALINITY, TEMPERATURE, OXYGEN CONTENT AND HYDROGEN-ION CONCENTRATION, LEHIGH VALLEY R.R. PIER A, JERSEY CITY, N. J.

FIG. 75—SALINITY, TEMPERATURE, OXYGEN CONTENT AND HYDROGEN-ION CONCENTRATION, SOUTH 3RD STREET PIER, AMERICAN SUGAR REFINING CO., BROOKLYN, N. Y.

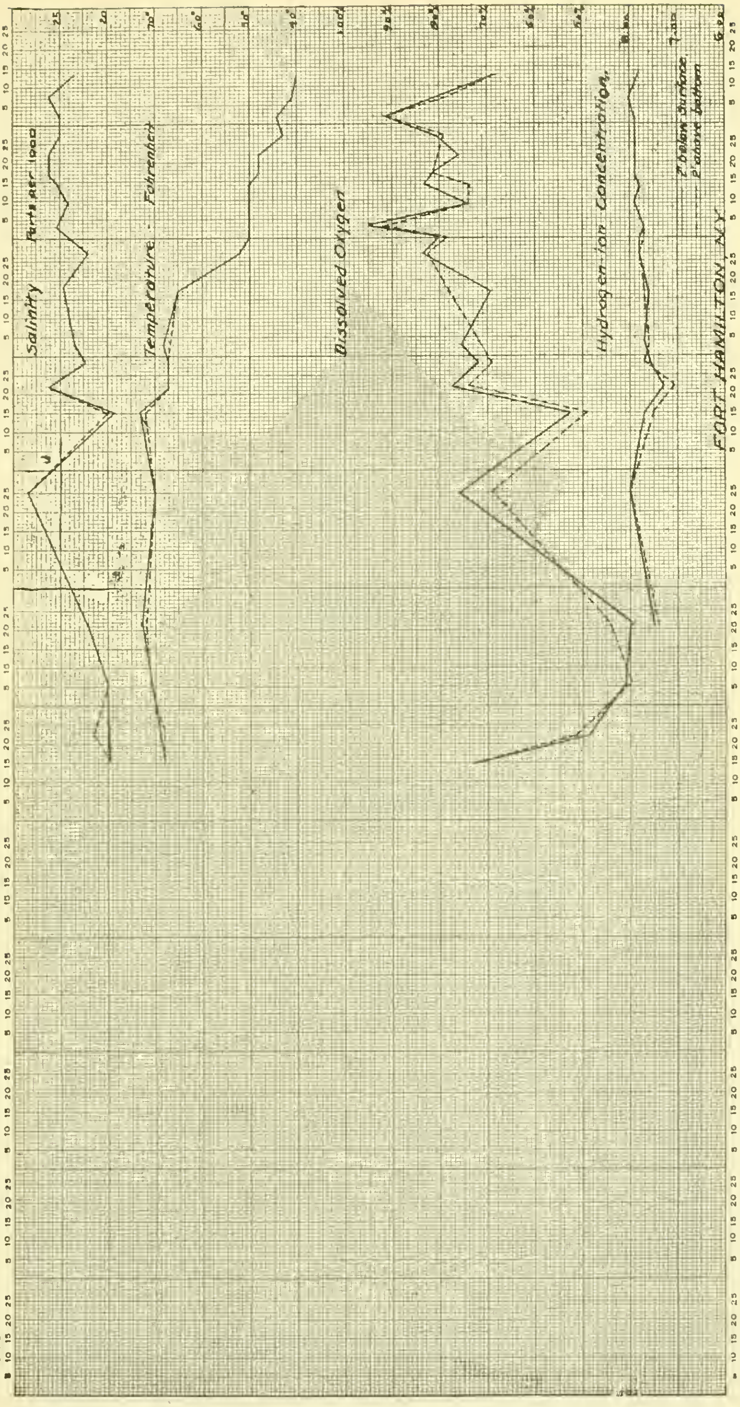


FIG. 76—SALINITY, TEMPERATURE, OXYGEN CONTENT AND HYDROGEN-ION CONCENTRATION, FORT HAMILTON, N. Y.

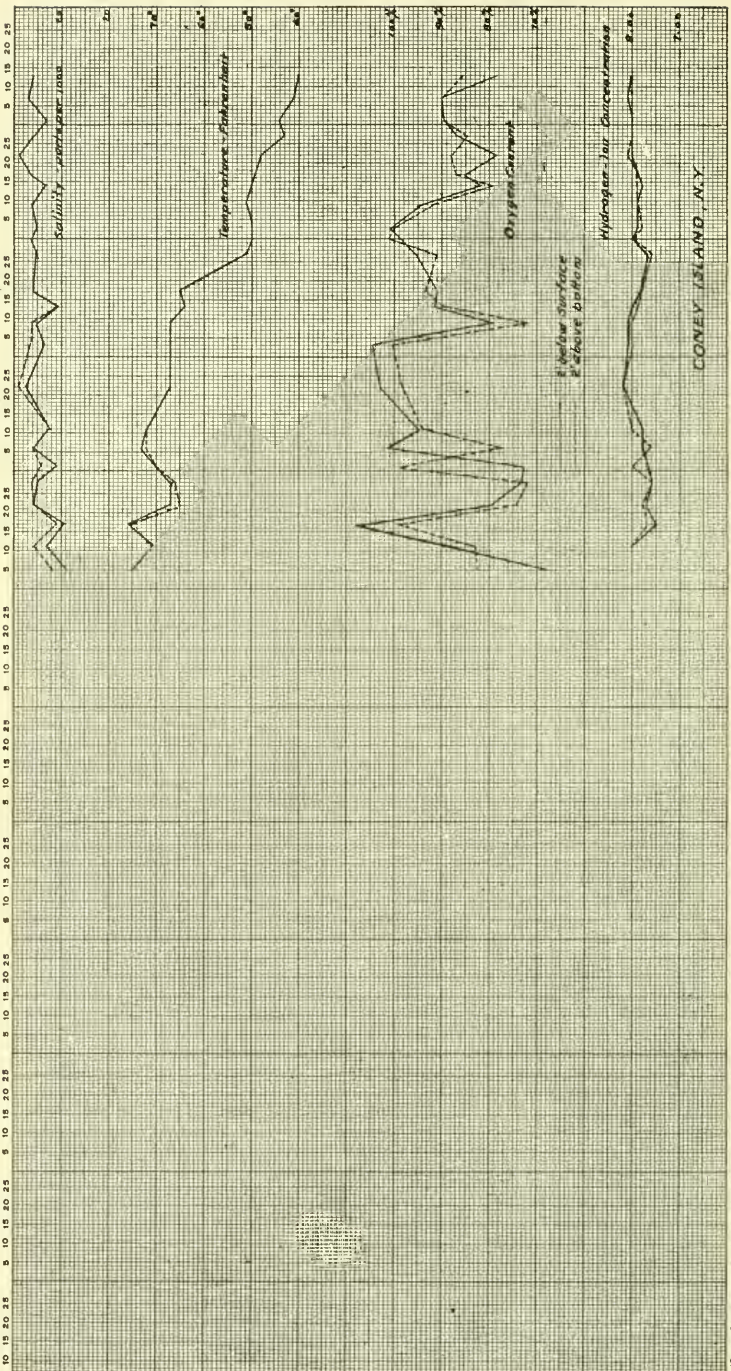


FIG. 77—SALINITY, TEMPERATURE, OXYGEN CONTENT AND HYDROGEN-ION CONCENTRATION, CONEY ISLAND, N. Y.

crete piles recently but they are not old enough to give valuable data as to their probable life in this vicinity.

Conclusions

1. Those sections of the harbor in the East, Harlem and Hudson Rivers and Newark Bay, are not apparently in any great danger of attack, though cases of sporadic attack may occur even here, especially near the Battery.

2. The structures in the Upper Bay and Kill van Kull are, with the exception of those on the Long Island shore, continuously under light attack, and a serious attack is possible at any time.

3. Structures in the Lower Bay, including Jamaica Bay and Raritan Bay, are subject to attack from both shipworms and *Limnoria*, and any structure is likely to be very heavily attacked at any time.

4. Structures in the Lower Bay should be protected and protection should be given structures on the west side of the Upper Bay and should be seriously considered for those on the east shore of North River.

5. The record of concrete structures is not such as justifies the drawing of conclusions regarding them.

NEW JERSEY COAST AND DELAWARE BAY

Description

The coast line of New Jersey and Delaware Bay (Fig. 78), is in general low and sandy, backed by woods and with many outlying sand shoals. The prevailing winds are westerly, subject, however, to many variations at all seasons. Tidal currents are weak, averaging at strength only about 0.2 knots.

Manasquan Inlet, about 17 miles south of Navesink Lighthouse, has a narrow, changeable entrance with a depth across the bar in 1914 of about three feet.

Barnegat City is located on Barnegat Inlet, the entrance to the bay of the same name. In this vicinity shoals with depths less than 30 feet extend 2 miles off shore. Beach Haven is 14 miles southwest of Barnegat City, and 20 miles north of Atlantic City. Atlantic City is located on the south side of Absecon Inlet, which is being improved to a channel depth of 12 feet and width of from 300 to 600 feet. The test board is located on the Atlantic City Steamship Terminal Wharf on Clam Creek, about two-thirds of a mile from Absecon Inlet.

Test boards were installed at representative points in Delaware Bay—two at the entrance, Cape May and Lewes, and five distributed throughout the length of the bay on or near the channel. This channel is maintained at a minimum depth of 30 feet as far as Philadelphia, except for two isolated shoals—one with a depth of 29.7 feet on Baker Range, and the other with a depth of 28.9 feet on Liston Range. The mean rise and fall of tide at Delaware Breakwater is 5.1 feet with 4.5 feet as far as the Quarantine Station, at which point it becomes 6 feet. It is also 6 feet at the mouth of the Christiana River.

The mean velocity of tidal currents is 2 knots on flood and 2.3 knots on ebb, the maximum velocity recorded being 3.2 knots during a southeasterly and 3.6 knots during a northwesterly gale, respectively.

Marine Borers

Past History—Both shipworms and crustacean borers have always been troublesome along the New Jersey Coast. An Army survey boat was dam-

aged by shipworms in 1903 while stationed for only six weeks in the Shrewsbury River. The Pennsylvania Railroad reports damage to its structures shown in the table under "Methods of Protection."

In 1913 the West Jersey & Seashore Railroad protected the piles of the center pier of its Grassy Sound drawbridge near Wildwood on the Inland waterway with concrete casing. On account of the deterioration of the concrete, the piles were attacked by marine borers and it was necessary to remove all the old concrete in 1920 and to build new casings.

An inspection made by this company in 1922 disclosed evidence of marine borer (shipworm) attack at the following locations:

Pavilion	Absecon Inlet	Atlantic City
Pavilion	Little Egg Harbor Inlet	Longport, N. J.
Bulkhead	Little Egg Harbor Inlet	Somers Point, N. J.
Bridge	Weakfish Creek	South of Corson's Inlet
Bridge	Middle Thoroughfare	South of Corson's Inlet
Bridge	Corson's Inlet	Corson's Inlet
Bridge	Ludlam's Thoroughfare	North of Sea Isle City
Bridge	Beach Thoroughfare	Atlantic City
Bridge	Townsend Inlet	Townsend Inlet

In Delaware Bay both shipworms and crustacean borers are known to exist in the vicinity of Cape May and Lewes. The upper portion of the Bay seems to be free from shipworms. *Limnoria,* however, has been found at a point 30 miles above the entrance.

Committee Investigations—Standard test boards were installed as follows:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Point Pleasant, N. J	77	N. J. Board of Commerce and Navigation	Aug. 16, 1922	0.0	6.0
Barnegat City, N. J.—Sunset Hotel Dock	76	N. J. Board of Commerce and Navigation	Aug. 16, 1922	0.0	6.0
Beach Haven, N. J.—Public Wharf	78	N. J. Board of Commerce and Navigation	Aug. 21, 1922	1.0	6.0
Atlantic City, N. J.—Atlantic City, S. S. Wharf	80	N. J. Board of Commerce and Navigation	Aug. 21, 1922	2.0	6.0
Cape May—Delaware Naval Air Station Marine Dock	YD-401	Navy	Aug. 6, 1922	0.0	6.5
Lewes, Delaware	Pa-4	Pennsylvania R.R	Oct. 9, 1922	......	......
Delaware Bay—14-foot Bank	A-38	Army	Nov. 17, 1922	1.0	8.0
Delaware Bay — Miah Maull Lighthouse	A-39	Army	Nov. 16, 1922	9.0	6.0
Delaware Bay—Elbow of the Ledge	A-40	Army	Nov. 16, 1922	9.0	11.0
Delaware Bay—Reedy Island Quarantine	A-41	Army	Nov. 16, 1922	17.0	10.0
Delaware Bay—Mouth of Christiana River	A-42	Army	Nov. 17, 1922	5.0	10.0

The test boards on the New Jersey coast were maintained only during the season of 1922 and therefore no comparison of the attack in the seasons of 1922 and 1923 can be made, but it is reported that the attack in Barnegat Bay at the station of the New Jersey Agricultural Experiment Station was much lighter in 1923 than in 1922.

The results of the inspection of test blocks are as follows:

No. 77—*Teredo navalis* in large numbers appeared on the first block to be


MAP SHOWING LOCATION OF
TEST BOARDS
DELAWARE BAY
NEW JERSEY & DELAWARE
1923
NAUTICAL MILES
0 1 5 10
YARDS
0 5,000 10,000
N
WILMINGTON
A-42
A-41
BELL
A-40
REED HORN
A-39
REED HORN
A-38
REED HORN
REED HORN
CAPE
MAY
YD-401
PA-4
LEWES

ag
Sh
tu

ce
wa
cr
m

bo

ex
se
po

lo

Poi

Bar
H
Bea
W
Atla
C
Cap
S
Lew
Del
Del
L
Del
L
Del
Q
Del
ti

sea
19
Ba
mu

removed, and specimens reached an average length of 3 inches by October 20, after which time there seemed to be no growth. Test blocks were thoroughly honeycombed. Associated organisms were Bryozoa and *Mytilus* with a few specimens of *Limnoria.*

No. 76—*Teredo navalis* attacked promptly and in two months the blocks were thoroughly honeycombed. The animals reached a length of over 3 inches in the same time. Associated organisms were *Balanus* and Green Algae.

Dr. Thurlow C. Nelson reports, when studying oyster culture in Barnegat Bay for the New Jersey Agricultural Experiment Station, that he found one of the platforms used for collecting oyster spat to have been completely destroyed by *Teredo navalis* in five weeks. Dr. Nelson also reports the presence of *Bankia gouldi* in Barnegat Bay. During the summer of 1921 when this damage was done by *Teredo navalis* the salinity of the water was unusually high.

No. 78—*Teredo navalis* attacked this board promptly, the first block after two weeks' immersion containing large numbers. Specimens reached a length of about 3 inches before the end of the season of activity. Associated organisms were Bryozoa, Green Algae, and a few specimens of *Limnoria.*

No. 80—The first block removed, after 19 days' immersion, contained 50 to 75 specimens of *Teredo navalis* from 1/16-inch to ⅛-inch in length, and within one month the maximum length had increased to 2 inches. These test blocks were thoroughly honeycombed in three months.

Limnoria appeared in considerable numbers and the associated organisms were *Balanus* and Bryozoa.

YD-401—Unfortunately, the Naval detachment left this station about one month after the board was immersed and only two blocks were received, both containing several immature shipworms. The growth of *Balanus* was heavy.

Pa-4—No shipworms appeared on this board until August, 1923, ten months after the board was immersed, but one specimen of *Bankia gouldi* was found in the block removed August 11, 1923. Only a few animals were found, the longest being about 5½ inches long. The associated organisms *Balanus* and Bryozoa, ordinarily indicating the possibility of shipworm attack, were found about six months before the first *Bankia* appeared.

A-38 and A-39—These boards were lost through the breaking of moorings, and replaced twice. No organisms of any kind were found on the few blocks received.

A-40—Three boards were lost at this station, none of them remaining in service three months. No organisms were found on the first two, while the third, which was in service between June 5 and August 15, 1923, showed the associated organisms of Green Algae, *Tubularia* and Bryozoa (*Lepralia*), but no borers.

A-41 and A-42—No life of any kind appeared on the 32 blocks received from these two stations.

Methods of Protection

Several of the piers at Atlantic City and other resorts have piles protected from borer attack by concrete jackets, removable wooden sheathing and other methods, but no definite service records were obtainable except that

the City Engineer of Atlantic City states that 1-inch creosoted sheathing boards are destroyed in ten years.

The Pennsylvania Railroad (P. & B. H. R. R., P. & L. B. R. R. and W. J. & S. R. R.) reports the following structures:

Location or Name	Original Date Constructed	Rebuilt	Rebuilt Creosoted Timber	No. of Piles	Present Condition
Br. No. 3.96, Manahawken, N. J. . .	1886	. . . .	1897	124	Fair.
Trestle Br. No. 5719, Barnegat Bay .	1880	1885-1899	1899	3500	20 per cent attacked.
Trestle Br. No. 3.40, Barnegat Bay. .	1886	. . . .	1896-7-8	1564	Slight attack.
Trestle Br. No. 4.31, Barnegat Bay. .	1886	. . . .	1897	60	Slight attack.
Trestle Br. No. 4.54, Barnegat Bay. .	1886	. . . .	1897	160	Fair.
Trestle Br. No. 4.77	1886	1893	1897	288	Slight attack.

The Pennsylvania Railroad also reports that creosoted timber in service thirty years at Townsend Inlet had been attacked, but that no attack had been noticed on timber of more recent date.

Substitutes for Timber

There are a number of concrete and some metal structures at the various resorts in this district, but they are most of them exposed to the wave action of the open ocean and are not therefore suitable for a study of the durability of concrete or metal in salt water.

Conclusions

All wooden structures in salt water on the New Jersey coast are liable to a destructive attack by shipworms. Piles may be destroyed in two or three years, and therefore if a structure of any importance is to be built the piles should be protected.

The records furnished by the Pennsylvania Railroad indicate that well creosoted and undamaged piles may be expected to have an average life exceeding twenty years.

Probably on account of the shallow and consequently warmer water of the New Jersey coast the season of inactivity is shorter than in New York and New England. It may be expected to extend from about October 1 to June 15.

On account of the difficulties experienced in maintaining the test boards in Delaware Bay the information is too fragmentary to permit any other conclusions than that shipworms are active and destructive at Cape May, and that *Bankia gouldi* is present at Lewes.

BALTIMORE HARBOR AND VICINITY

Marine Borers

Past History—No authentic record of the finding in the past of either molluscan or crustacean borers in Baltimore Harbor (Fig. 79), has come to the attention of the Committee. Marine borers have been known to destroy the pile supports of a bridge over the Severn River at Annapolis in four years' time. A light attack on a pile bridge of the Pennsylvania Railroad over Bear Creek at Sparrows Point was reported as having occurred in 1917, about 10 per cent of 100 piles being affected. Repairs to the Lighthouse Wharf at Washington, built in 1910, were made necessary on account of damage by *Limnoria.*

Committee Investigations—On account of the installation of sanitary sewers and the consequent cleansing of the water, it was thought advisable to place test boards throughout the harbor. A board was also placed at the Lighthouse Wharf, Washington, (Fig. 81). The boards installed were as follows:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Baltimore—					
Canton Ore Pier	PA-1	Pennsylvania R. R.	Sept. 1, 1922	0.5	9.0
Clinton St. Pier	PA-2	Pennsylvania R. R.	Sept. 1, 1922	12.0	10.0
Bear Creek Bridge	PA-3	Pennsylvania R. R.	Sept. 1, 1922	1.5	15.0
Hanover St. Bridge	BH-1	Harbor Board of Baltimore	Sept. 15, 1922	......	......
Fort McHenry	BH-2	Harbor Board of Baltimore	Sept. 15, 1922	......	......
Coast Guard Depot, So. Balt.	CGD-1	Coast Guard	Oct. 1, 1922	0.5	8.0
Curtis Bay	B&O-5	Baltimore & Ohio R. R.	Oct. 15, 1922	1.0	21.0
Locust Point	B&O-6	Baltimore & Ohio R. R.	Oct. 15, 1922	1.0	14.0
Standard Oil Plant	SO-4	Standard Oil Co.	Nov. 1, 1922	......	......
Locust Point	ASR AtoC	American Sugar Refining Co.	March 1, 1923	......	......
Washington, D. C.—					
Lighthouse Wharf	L-5-1	Lighthouse Dept.	Oct. 31, 1922	......	......

With the exception of evidence of slight working by *Limnoria* on one of the A. S. R. boards, no signs of either shipworms or crustacean borers have been noted on any of the blocks from these stations. Other organisms noted were *Balanus*, Bryozoa and Mytilus. No life of any kind was perceptible on blocks from boards PA-2, BH-2, B&O-5 and 6, SO-4, ASR-A and B and L-5-1. Figure 80 shows records of salinity, temperature, oxygen content and hydrogen-ion concentration observed by the American Sugar Refining Company at the site of their test boards.

Methods of Protection

Protection against marine borers in Baltimore Harbor has been considered to be unnecessary.

Substitutes for Timber

Concrete—The Committee has collected no service records of concrete structures in Baltimore Harbor.

Conclusions

It would appear that protection against marine borers is unnecessary in the immediate vicinity of Baltimore and Washington. Because of the purification of the waters in the harbor of Baltimore, it seems somewhat doubtful whether this apparent immunity can be considered permanent and unprotected structures should receive careful and frequent inspection. Locations at Sparrows Point and Annapolis should be looked on with more suspicion than those at Baltimore proper. The presence of *Balanus* and Bryozoa on board PA-3 indicates that the existence of shipworms is probably not impossible.

NORFOLK HARBOR

Description

The approach to Norfolk Harbor (Fig. 82), is by way of Hampton Roads, sixteen miles west of Cape Henry, the connecting channel having a minimum

depth of 38 feet. A channel dredged to a minimum depth of 40 feet leads from Hampton Roads south to the harbor proper which is located at the mouth of the Elizabeth River. The three branches of the river (Eastern, Southern and Western) form the waterfront of Norfolk, Berkeley, Portsmouth, Port Norfolk and West Norfolk. The Naval Operating Base and important railway terminals are located on the dredged channel leading to Hampton Roads. Extensive waterfront structures consisting of the ter-

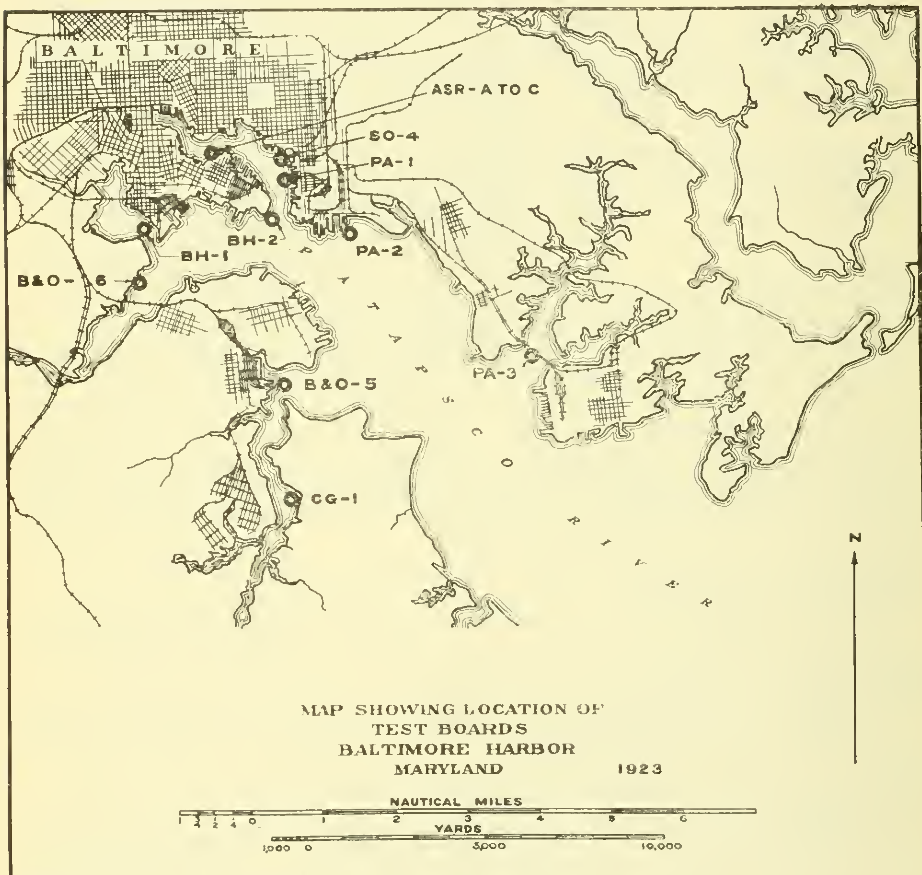


FIG. 79

minals of the Chesapeake and Ohio Railway, and the plant of the Newport News Shipbuilding and Dry Dock Company are located at Newport News directly across the Roads, at the mouth of the James River.

The mean tidal range is 2.78 feet and the extreme range recorded is 6.9 feet, observed at the upper end of the harbor at the U. S. Navy Yard. Tidal currents vary between the same limits from one to six miles per hour, the average velocity at the Naval Operating Base being approximately three miles per hour.

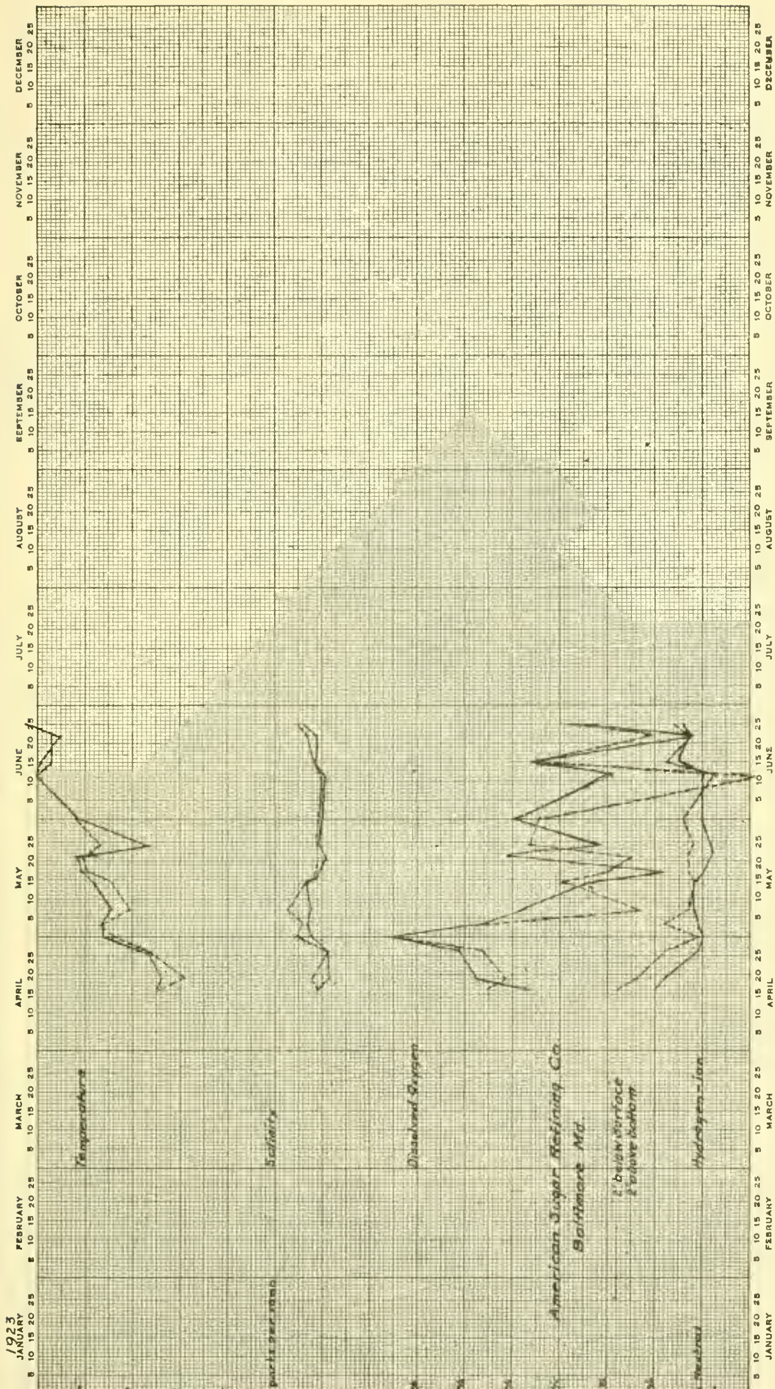


Fig. 80—Salinity, Temperature, Oxygen Content and Hydrogen-ion Concentration, American Sugar Refining Co.'s Pier, Baltimore, Md.

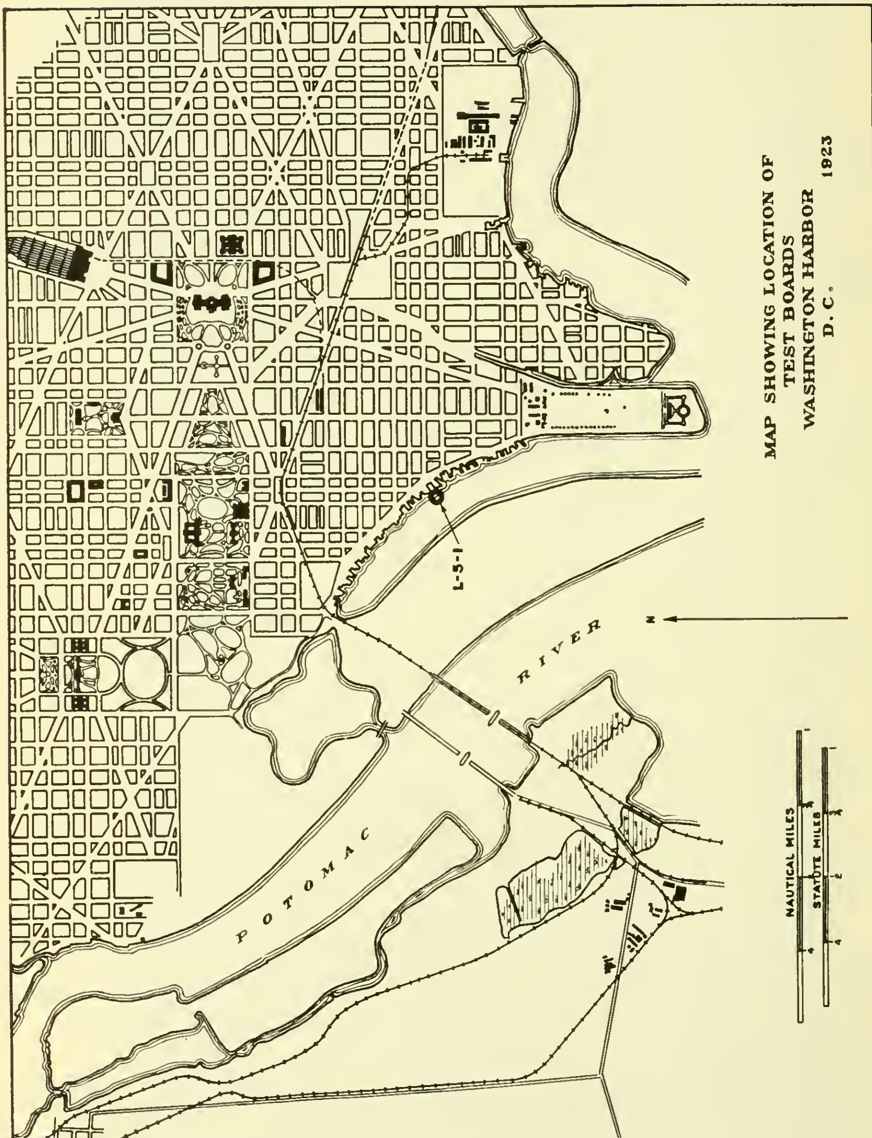

MAP SHOWING LOCATION OF
TEST BOARDS
WASHINGTON HARBOR
D. C.
1923
L-5-1
POTOMAC
RIVER
N
NAUTICAL MILES
STATUTE MILES

Fig. 81

Storms are frequent and of high intensity, the wind often reaching a velocity of ninety miles per hour.

Into the Elizabeth River is dumped the entire sewage of Norfolk and Portsmouth, which, together with industrial wastes, pollute the water to a fairly high degree, including both oil and chemical pollution, the latter emanating principally from a number of fertilizer manufactories. The untreated sewage of Newport News is discharged into Hampton Roads.

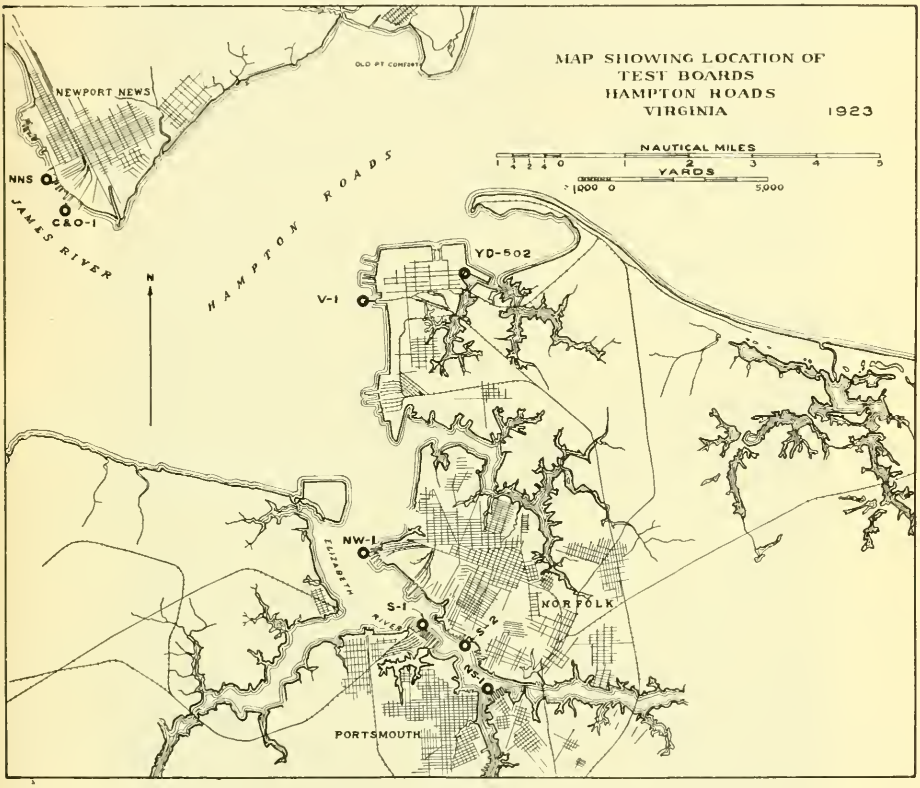


FIG. 82

The temperature of the water varies from 30 to 85 deg. Fahr.; the salinity from 5 to 23 parts per thousand. (See Figures 83, 84, 85.)

Marine Borers

Past History—Shipworms and crustacean borers have always been present at Norfolk—the latter to a less extent—and of late years all timber which is destined to be exposed for any length of time has been protected. The greatest intensity of attack is found at Sewall Point, where a number of foundation piles were destroyed during the construction of a pier. The Gilbert Street Pier failed completely within four years after construction. Farther up the river at the Navy Yard the attack has been found to be less

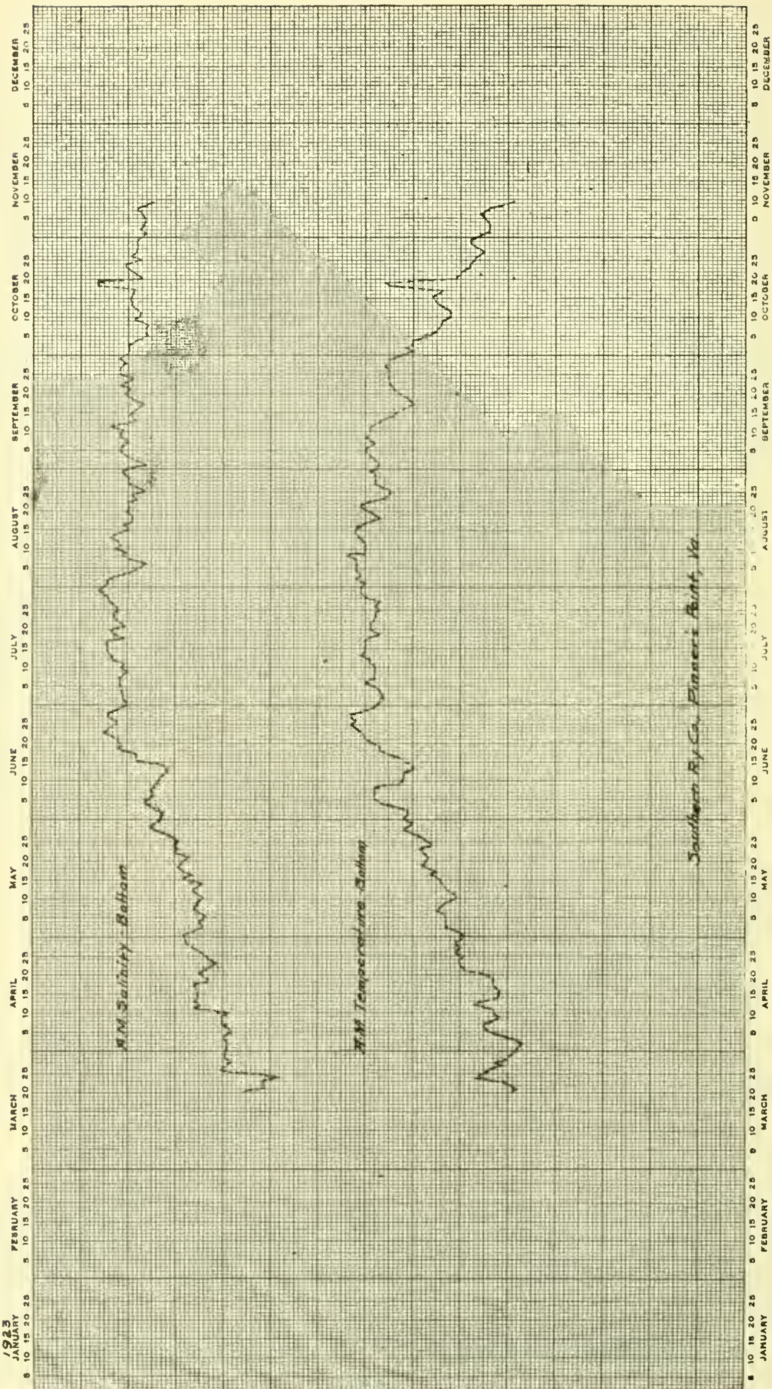


FIG. 83—SALINITY AND TEMPERATURE OBSERVATIONS, SOUTHERN RY. CO.'S PIER, PINNERS POINT, VA.

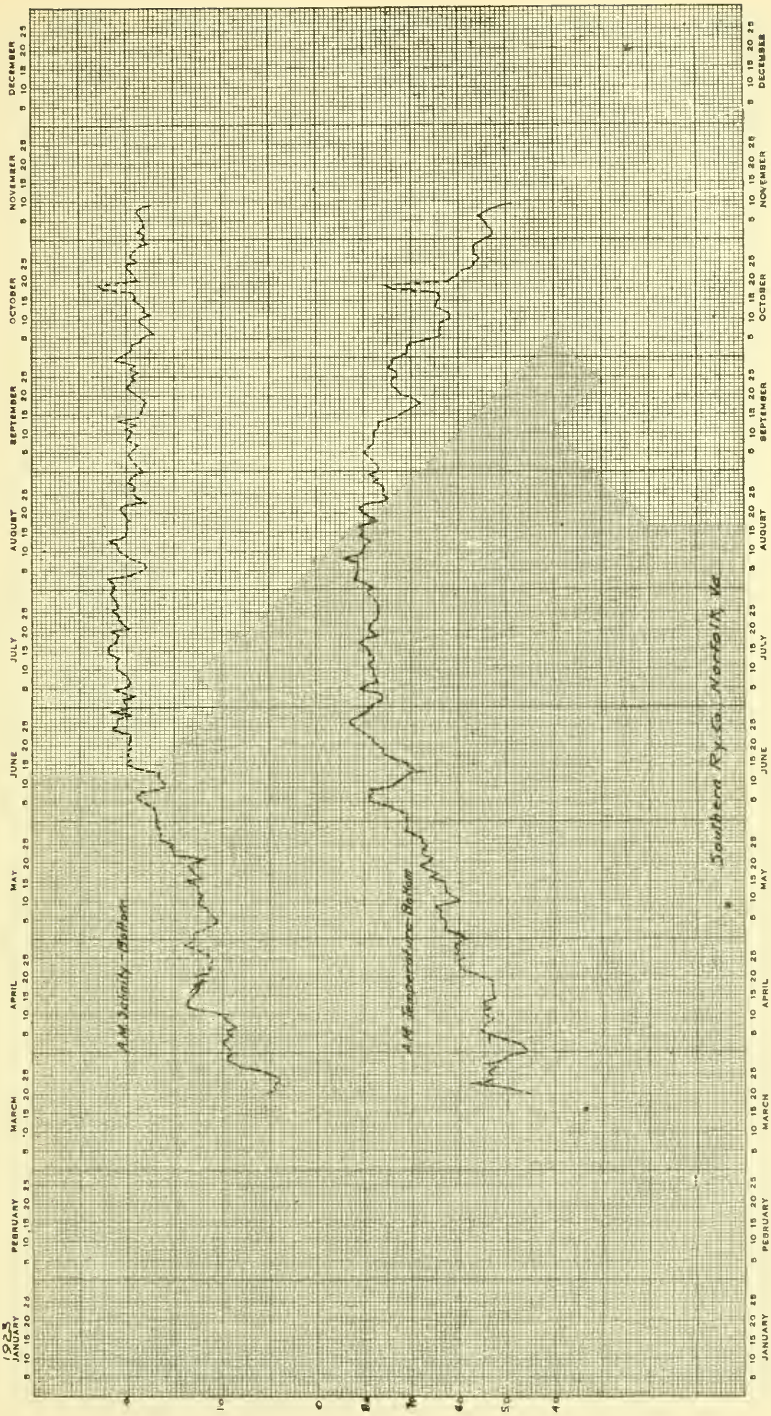


FIG. 84—SALINITY AND TEMPERATURE OBSERVATIONS, SOUTHERN RY. CO.'S PIER, NORFOLK, VA.

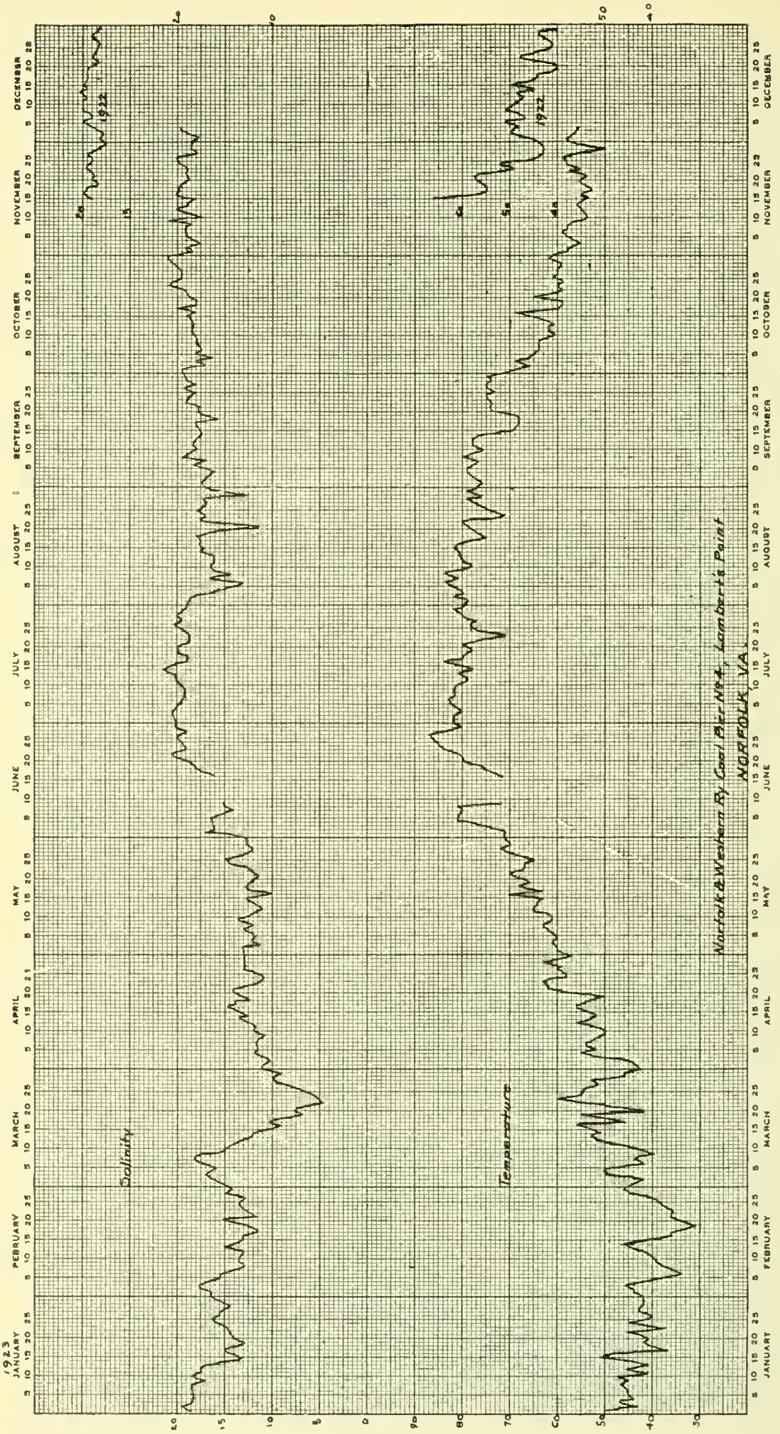


FIG. 85—SALINITY AND TEMPERATURE, NORFOLK & WESTERN RY. CO.'S COAL PIER NO. 4, NORFOLK, VA.

severe. However, the practice of protecting timber is general throughout all parts of the harbor.

The average life of untreated timber has been variously estimated from two years at Sewall Point and the Naval Operating Base, to five years in the Eastern Branch of the Elizabeth River and sometimes as much as eight or ten years in the extreme inner harbor.

Standard test boards were located as follows:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Bousch Ck. Bulkhead	YD-502	Navy	Sept. 15, 1922	......	......
Sewall Point	VA-1	Va. Ry	Sept. 12, 1922	0.5	20.5
Pier 4, N. & W. Ry	NW-1	N. & W. Ry	Sept. 1, 1922	3.0	14.3
Bulkhead, N. S. Ry	NS-1	N. S. Ry	Oct. 20, 1922	1.0	9.0
Pinners Point	S-1	So. Ry	Oct. 1, 1922	2.0	8.2
So. Ry. Pier	S-2	So. Ry	Oct. 1, 1922	2.0	8.2
Pier 1, C. & O. Ry	CO-1	C. & O. Ry	Sept. 1, 1922	1.0	9.5
Newport News Shipbuilding and Drydock Plant	NNS-1-13	N. N. S. B	Jan. 30, 1923	Various	Various
Great Bridge, Va	A-1	Army	Sept. 16, 1922	1.0	6.8

The results of inspections of test blocks are as follows:

YD-502—Only four blocks from this board were examined, the third removed December 20, containing the only shipworms, which proved to be *Bankia gouldi.* Associated organisms were *Balanus* and Bryozoa.

VA-1—Many shipworms were found in block 2, removed October 17. The majority of these were *Teredo navalis*, the remainder *Bankia gouldi.* This proportion prevailed in the succeeding blocks in each of which the shipworms numbered from 100 to 150. On February 15, 1923, the board, together with the remaining original (Nos. 10-24) and the replacement (Nos. 25-33) blocks was removed from the water and forwarded for examination, the result of which determined the end of the season of activity as occurring between October 15 and November 1. After the latter date growth practically stopped, as was evidenced in finding live and healthy specimens of only 2 mm. length on the date of examination, February 25. These specimens were found in blocks 25 and 26, placed October 1 and 15, respectively. Neither block 27, placed November 1, 1922, nor any of the succeeding blocks contained shipworms. A new board of revised type was placed, and the first shipworms (*Bankia gouldi*) appeared in block 4 removed July 7, 1923. *Teredo navalis* was found one month later. No specimens of *Limnoria* were found on any of the blocks. Associated organisms were *Balanus*, Bryozoa and Ostrea.

NW-1—Shipworms first appeared in block 2, removed October 2, 1922. The succeeding blocks, 3 to 22 inclusive, contained ten specimens more or less, about equally divided between *Teredo navalis* and *Bankia gouldi.* Block 23, removed August 15, 1923, and succeeding blocks 24-27 inclusive, showed complete destruction by *Bankia gouldi* of the 1923 brood. A few specimens of *Limnoria* were found. Associated organisms were *Balanus,* Bryozoa and Ostrea.

NS-1—These blocks, placed late in the season, showed no life of any kind until No. 5, removed February 3, 1923, was reached, on which there appeared a few barnacles. Block 10, removed August 4, 1923, and block 11,

removed September 4, 1923, contained 10 and 50 specimens of *Bankia gouldi* respectively. Associated organisms were *Balanus* and Bryozoa. No specimens of *Limnoria* were found.

S-1—A single specimen of *Teredo navalis* belonging to the 1922 brood was found in block 15, removed May 16, 1923. Block 19 contained one specimen and block 20 seven specimens, the largest one being 10 inches in length. Fifty to 100 specimens of *Bankia gouldi* appeared in blocks 21, 22 and 23. Both blocks 24 and 25, removed October 1 and 16 respectively, were well filled with *Bankia gouldi*. No *Limnoria* was found. Associated organisms were *Balanus* and Bryozoa.

S-2—One specimen of *Teredo navalis* was obtained from each of blocks 10, 17, 18 and 19, the lengths of their tubes being ¼, 2¼, 3 and 5 inches, respectively. These blocks were removed March 1, June 16, July 2 and July 16, 1923, respectively. Block 20, removed August 1, contained 10 shipworms of large size—both *Teredo navalis* and *Bankia gouldi* in about equal proportions. Block 21, removed two weeks later, contained about 20 specimens. Blocks 22 and 23 contained each about 50 specimens of *Bankia gouldi* and few if any of *Teredo navalis*. Blocks 24 and 25, the latter removed October 16, were filled with *Bankia gouldi*. No specimens of *Limnoria* were found. Associated organisms were *Balanus* and Bryozoa.

CO-1—Twenty-four blocks in all were examined, the last one being removed August 16, 1923. With the exception of the first one, all blocks contained each from 4 to 16 shipworms about equally divided between *Teredo navalis* and *Bankia gouldi*. No specimens of *Limnoria* were found. Associated organisms were *Ostrea*, *Balanus* and Bryozoa.

NNS-1—This test comprised 13 galvanized plates to each of which were attached a set of 48 test blocks 2 inches by 4 inches by 5 inches, 24 being of the sap and 24 of the heart wood of short leaf yellow pine. They were placed in the water January 30, 1923, too late for the 1922 and far in advance of the 1923 season. The first shipworms appeared in the tenth series of blocks removed July 16, 1923, both *Teredo navalis* and *Bankia gouldi* attacking the heart and sap wood impartially. The attack of *Bankia gouldi* grew in intensity with the succeeding blocks, the final series (No. 16, removed October 1) being entirely filled with shipworms excepting those blocks which being at the top of certain plates were not continuously submerged. Associated organisms were *Balanus* and Bryozoa.

A-1, (Fig. 86)—Twenty-five blocks were examined, of which blocks 2, 6, 8, 9, 10, 14, 15, 17, 20, 21 and 22 each contained one specimen of *Bankia gouldi*. Associated organisms were *Balanus*, *Mytilus*, Bryozoa and numerous non-boring crustacea.

From the foregoing, it will be seen that a period of immunity of about eight months between October 15 and June 15 may be expected in this territory. This period will vary slightly from these dates according to the variations found in temperature.

Salinity and temperature observations of the water of Norfolk Harbor were recorded by the Southern Railway Company and the Norfolk & Western Railway Company (Figs. 83, 84 and 85). Similar records were made by the Army at Great Bridge (Fig. 87), from which it was ascertained that there are long periods of little or no salinity, a condition which has hitherto been considered impossible for the continued existence of *Bankia gouldi*, and

which necessitates a revision of previous ideas as to immunity from this species.

Methods of Protection

Creosote Impregnation—The Seaboard Air Line finds piles treated with 16 pounds per cubic foot to be in good condition after eight years' service. The Norfolk & Portsmouth Belt Line Railroad finds 75 per cent of piles treated with 12 pounds per cubic foot to be in use after twenty years' service. The Southern Railway has been using 16-pound treatment, but considers this treatment too light and that it should be increased to 20 or 22 pounds. The New York, Philadelphia & Norfolk Railroad states that pine piles creosoted with 16 to 18 pounds of oil per cubic foot last 20 to 25 years—charred cypress piling from 15 to 18 years. The Atlantic Coast Line uses 16 to 18 pounds; the Virginian Railway, 12 to 16 pounds, piles being found in good condition after 15 years' service. The piles of the Norfolk & Western Railway docks, built between 1890 and 1892 at Lambert's Point, were treated with approximately 22 pounds of creosote, and analysis of three pile sections cut from piles in these piers in 1922 showed an oil content of from 0.9 pound to 4.2 pounds of creosote per cubic foot. Two of them had been attacked by *Bankia gouldi,* while the third, which was cut from a point above low water, was not attacked. The Norfolk Southern Railroad uses 20 pounds; the Chesapeake & Ohio Railway, 16 pounds. The experience of the Newport News Shipbuilding & Dry Dock Co. leads it to conclude that full-cell treatment is most successful, prolonging the useful life of some piles to 20 years. This company has experimented also with "Carbolineum," "Reeds Wood Preserver," copper paint and heavy red lead, the former two having no noticeable effect and the latter two good until pierced. The U. S. Lighthouse Service uses piling impregnated with 20 pounds of creosote oil to the cubic foot for all *Teredo*-infested waters of this district.

Armor—Previous to the adoption of the practice of creosote impregnation, the Lighthouse Service covered all untreated piling for use in this district with copper, yellow metal or galvanized sheet iron. Sheet steel was used on the aprons at the entrance to Dry Dock No. 2, U. S. Navy Yard, to protect untreated timber. The metal is now said to be destroyed and the timber much affected by borers.

Substitutes for Timber

Iron and Steel—The following table shows the service record of metal supports:

Location	Structure	Date Built	Kind of Supports	Present Condition
Fort Monroe, Va.	Main Wharf.....	1889	Cast iron screw piles and columns	Good. Some replacements of columns broken by vessels.
Fort Monroe, Va.	Mine Wharf.....	1905 and 6	Cast iron columns covering creosoted piles cut off near bottom........................	Good. No repairs made.
Lambert's Point..	N. & W. Ry. Pier 2	1892	12-in. wrought iron piles on 4-foot cast iron bases.........	Good. No repairs made.

Concrete—Concrete has been employed by the Bureau of Yards and Docks, Corps of Engineers, Railways, etc. The Lighthouse Service has discontinued the use of reinforced concrete piles because of the first cost and

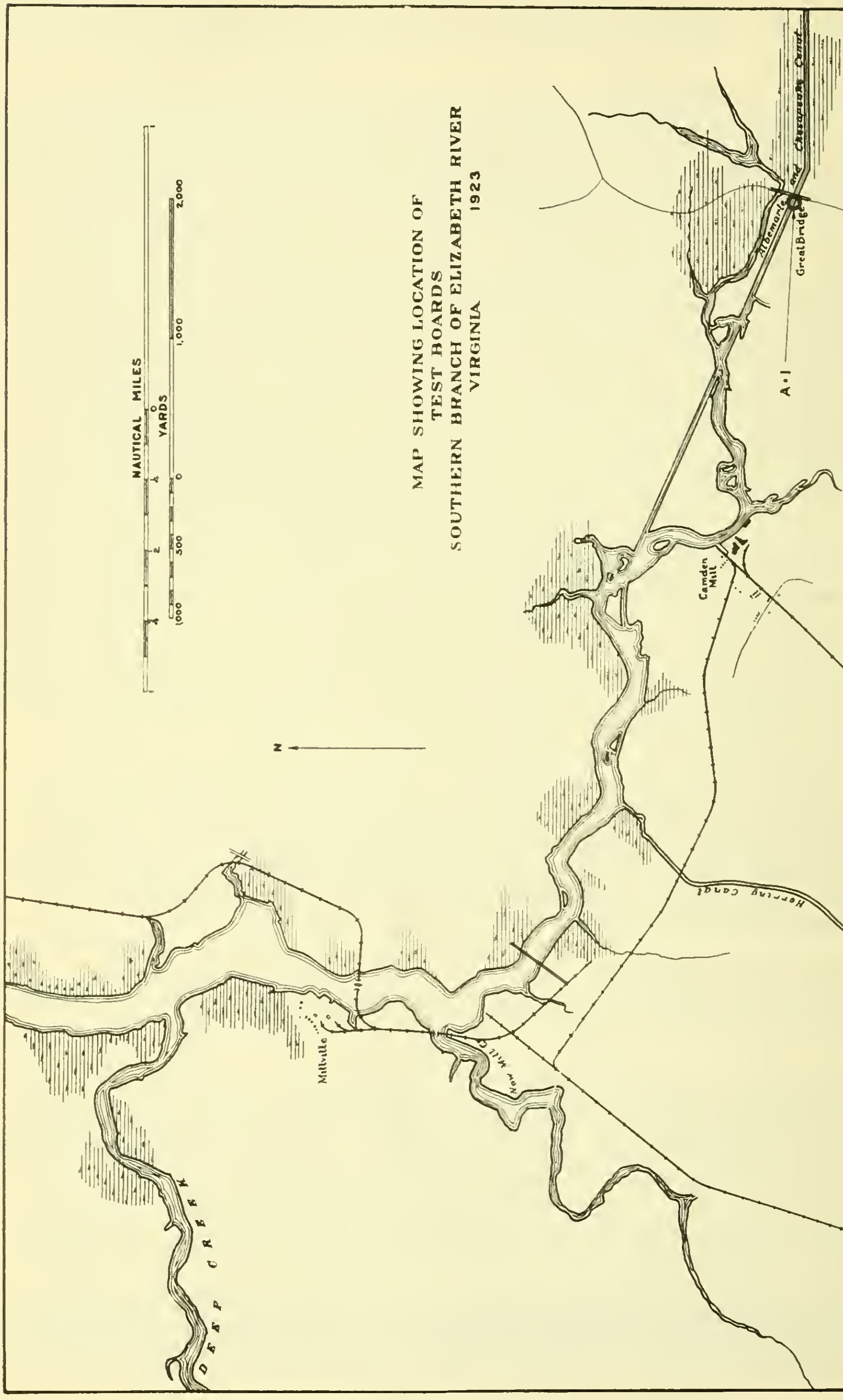

MAP SHOWING LOCATION OF
TEST BOARDS
SOUTHERN BRANCH OF ELIZABETH RIVER
VIRGINIA
1923
NAUTICAL MILES
YARDS
Albemarle and Chesapeake Canal
Great Bridge
A-1
Camden Mill
Herring Canal
Millville
DEEP CREEK

Fig. 86

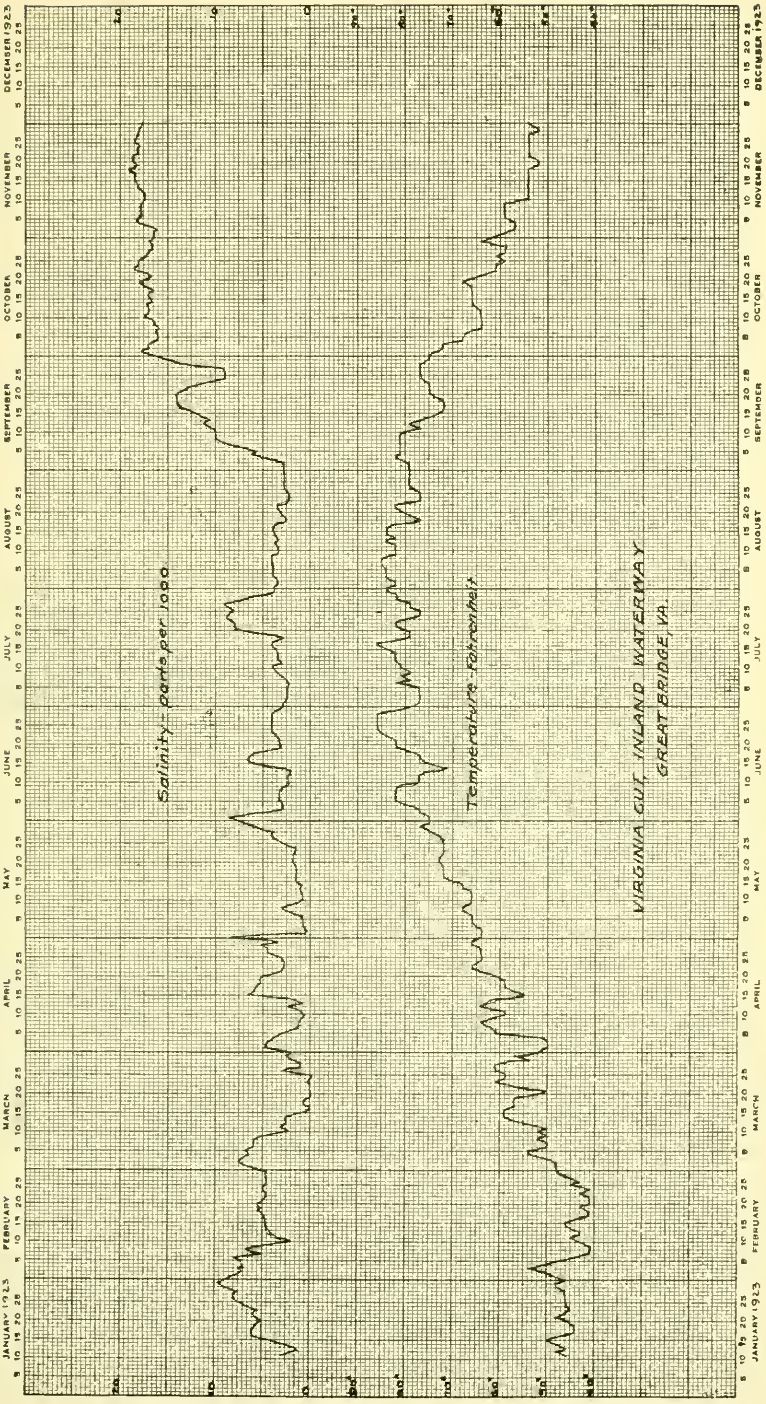


FIG. 87—SALINITY AND TEMPERATURE OBSERVATIONS, GREAT BRIDGE, VA.

the weakening of the piles by corrosion of the reinforcement. The structures reported are shown in the table below:

Location	Structure	Date Built	Present Condition
Lambert's Point...	N. & W. R. R. Coal Pier 3—3/8 in. steel plate cylinders filled with concrete............	1901	No repairs required. Corrosion of steel plate has not yet exceeded 1-32 in.
Lambert's Point...	Steel cylinders filled with concrete...	1913	Good. No repairs made.
Western Branch of Elizabeth River..	Same as above........................	1898	No repairs made. Deterioration of cylinders less than 10 per cent.
Cape Charles......	City Pier. Reinforced sheet piling bulkheads.	1910	Good. No repairs made.
Southgate.........	Terminal Pier. Reinforced concrete piles 16 in.x16 in............................	1917	No repairs—apparently in good condition.
U. S. Navy Yard...	Reinforced concrete walls poured between untreated timber sheet piling.............	1900	No deterioration due to exposure to salt water noticed.
U. S. Navy Yard...	Precast reinforced sheet piles made from ¾ in. gravel—reinforcing both plain and deformed. Mixture 1 2 4 and 1 1:2. Reinforcing cover 2 to 2½ in. Exposed to salt water from mud line to M. L.W., approximately 30 inches......................	1918-20	No sign of deterioration noticed.
Naval Operating Base............	Seaplane runways, solid fill type with concrete side walls carried below mud line and supported on untreated pine piles. Runways of reinforced concrete 6 in. slab—concrete beams on untreated pine piles buried in sand fill; constructed in dry inside steel cofferdam. Cured 15 days. Mixture 1:2:4 washed river gravel and sand, and Portland cement; of quaking consistency. Slab exposed to sea water. Side walls of same material of 1:2½:5 mixture, cured 30 days before removal of forms.........................	1919-20	Slab surfaces badly eroded by combined effect of salt water, wave action and abrasion from steel wheels of seaplane carriage trucks. The aggregate has raveled out to a maximum depth of approximately 3 in. over considerable area, the section between high and low water being particularly affected.
Naval Operating Base...........	Precast reinforced concrete sheet piles 10 in. x 16 in. Aggregate washed river gravel and Portland cement mixture 1:2:4 of quaking consistency. Piles kept moist 7 days after casting—then air seasoned 30 to 90 days. Some spalling during driving........	1919	Condition excellent.

Work on Municipal Terminal was started April, 1922. The first unit which is under construction consists of a marginal wharf 1,400 feet long; a pier 1,250 feet long and 494 feet wide; a grain elevator with storage tanks; drier, and conveyor galleries; together with the necessary railroad yards, roadways, fire, water and electric services.

The marginal wharf consists of reinforced concrete bearing piles and a reinforced concrete sheet pile wall under the inner face of the platform.

The pier is of the solid fill type surrounded on three sides by a reinforced concrete platform supported on reinforced concrete piles and with reinforced concrete sheet piling under the inner face of the platform.

The concrete piling in connection with these structures has just been completed. The depth of water provided around the pier and in front of the marginal wharf is 35 feet below M.L.W. The piles were cast on shore, and after being cast were allowed to season in air for a minimum of thirty days and were then driven with steam hammer pile drivers and hydraulic jets where necessary. The mixture used in casting the piles was 1 part Portland cement, 1½ parts of clean, sharp, washed sand, and 3 parts of clean washed quartz gravel screened to pass through a ¾-inch ring. Fresh water

from the Norfolk City Water Works was used in mixing. The concrete was conveyed from the mixer to the forms by concrete buggies and was thoroughly spaded after being dumped into the forms. The piles were kept covered with cloths which were kept dampened for the first ten days after same were cast. The first concrete pile in this structure was driven July, 1922, and the driving has continued practically continuously since this date. There is no evidence to date of any defective work in connection with this piling. Untreated timber used for construction purposes in connection with this work was badly attacked by borers during the construction period.

Conclusions

Unprotected timber structures should be expected to last from 2 to 5 years, except in the inner harbor, where a somewhat longer life is probable.

A period of immunity from attack of molluscan borers may be expected from November to June, inclusive.

Piles creosoted to refusal should have an average life of 20 years.

Wrought and cast iron show an excellent record, but the oldest structure recorded being only 35 years old, no estimate of average life is possible.

With one exception, the unprotected concrete is of too recent construction to justify conclusions as to its serviceable life.

BEAUFORT (N. C.) HARBOR AND CAPE FEAR RIVER

Description

Beaufort Harbor (Fig. 88), is the southern terminus of the Norfolk-Beaufort section of the inland waterway to which it is connected by a dredged channel of 12 feet minimum depth. At the entrance to the harbor, the tidal currents run with considerable velocity, especially during spring tides, and follow generally the direction of the channel. The Norfolk Southern Railroad test board is located on its bridge crossing this channel about equidistant from the towns of Beaufort and Moorhead City. The mean rise and fall of tide at this point is 3 feet. The Chemical Warfare Service has in place two test boards located near the site of the Marine Laboratory of the Bureau of Fisheries on Pivers Island.

Marine Borers

Past History—Shipworms were known to exist at Beaufort and at the mouth of Cape Fear River. The Army engineers estimate the life of unprotected piling as one season at the former and usually two seasons at the latter place.

Committee Investigations—Standard test boards were installed as shown in the following table:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Bridge over Newport River	NS-2	N. S. R. R.	Nov. 1, 1922	1.0	9.0
Pivers Island	CWS-1	Chemical Warfare Service	June 8, 1923	......	......
Pivers Island	CWS-2	Chemical Warfare Service	June 8, 1923	......	......

Salinity and temperature observations recorded by the Bureau of Fisheries at Pivers Island are shown on Fig. 89.

No test boards were installed in the Cape Fear River.

The result of inspection of the test blocks was as follows:

NS-2—The first block, removed on November 15, showed 20 specimens of *Limnoria* and 4 larval shipworms. Later blocks showed only a small number of shipworms (*Bankia gouldi*), with a length not exceeding $\frac{3}{8}$ inch, until block No. 8, removed April 5, showed about 50 specimens of *Bankia gouldi* with a length of $1\frac{1}{2}$ inches. The block removed one month later was filled with *Bankia gouldi* with a maximum length of about 4 inches.

On account of the destruction of the blocks the board was removed May 16, 1923, and replaced by a new board of the 1923 model. The examination

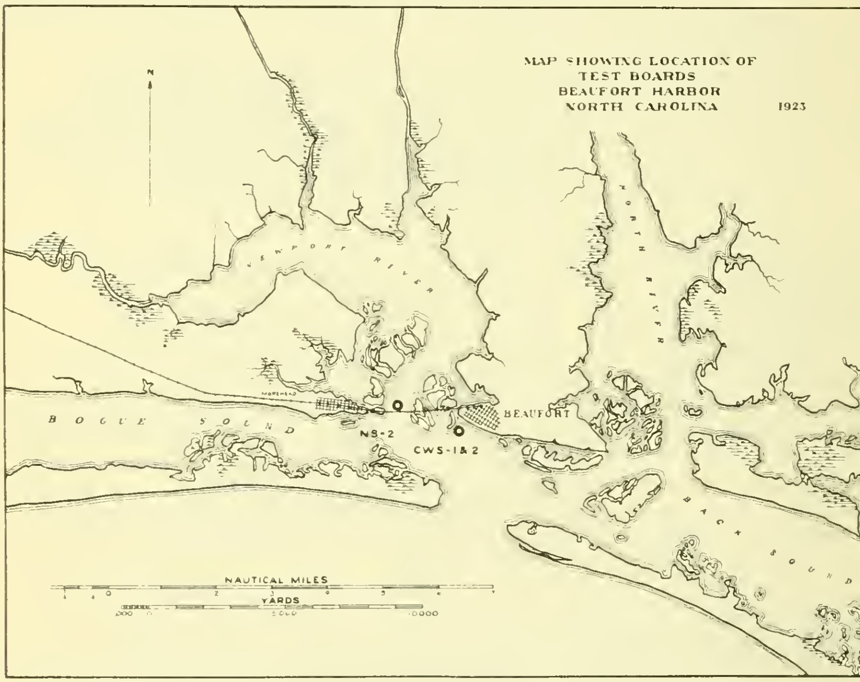


Fig. 88

of the old board showed that the season of activity for *Bankia gouldi* ended prior to December 1, 1922, and that of *Teredo navalis* began about May 1, 1923.

The new board, placed May 16, showed almost immediate attack by *Bankia gouldi* and *Teredo navalis*, and by July 7 the block was filled 95 per cent with *Bankia* and 5 per cent with *Teredo*, the longest *Bankia* being about 3 inches and the longest *Teredo* about 2 inches.

Some specimens of *Limnoria* were also found as well as the following associated organisms: *Balanus*, Bryozoa (*Lepralia* and *Bugula*), Anomia, Algae and Gasteropods.

CWS-1—Attack by *Bankia gouldi* was immediate and block 3, removed September 7, was completely filled with shipworms, principally *Bankia*

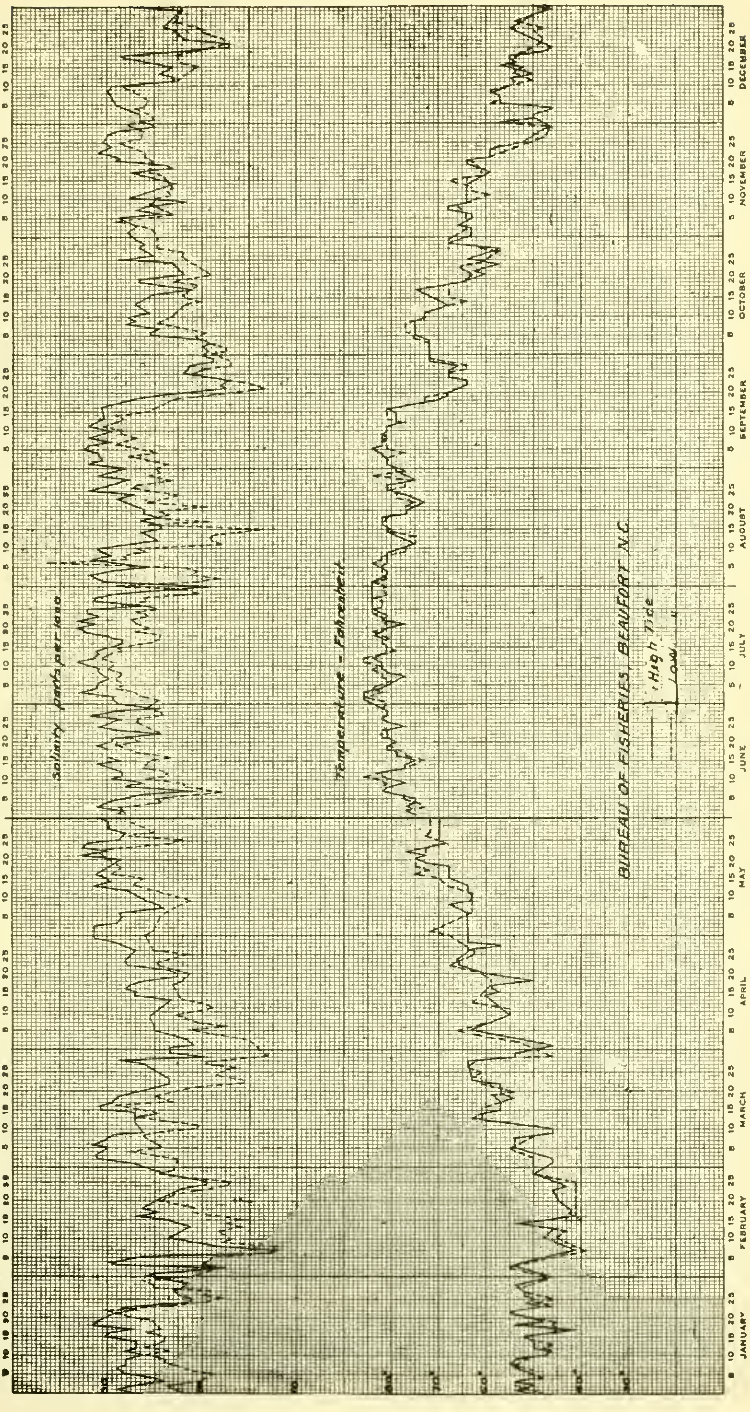


FIG. 89—SALINITY AND TEMPERATURE OBSERVATIONS, BEAUFORT, N. C.

gouldi, though several specimens of *Teredo* (*Psiloteredo*) *sigerfoosi* were found. The block removed October 10 was completely riddled and a larger proportion of *Teredo sigerfoosi* was found than in the preceding block. Associated organisms were the same as in NS-2, except for the absence of Algae and the presence of *Ostrea*.

CWS-2—Animals found were about the same as in CWS-1, as were the accompanying organisms.

Martesia was also found in test timbers maintained by the Chemical Warfare Service.

Methods of Protection

Creosote impregnation has been in general use and when sufficient absorption is obtained has proved fairly satisfactory. Piles treated with 20 pounds of dead oil tar per cubic foot were found to be in perfect condition after 20 years' service, and 14 pounds per cubic foot was found to be insufficient, piles so treated and driven in 1890 in the Engineers' Wharf at Southport having been found to be badly damaged in 1901.

"Protexol" was used for impregnating sheathing for the wooden hull of the floating plant belonging to the Corps of Engineers, U. S. A. Records show that, whereas unprotected sheathing lasts only one season, when so treated, three to five years' service is obtained.

Substitutes for Timber

Cast Iron—About the year 1900, the Quartermaster Department, U. S. A., built a wharf at Fort Caswell, supported by cast iron piling, which is reported to be in good condition at present.

Concrete—In 1912-13 the Lighthouse Service built 32 reinforced concrete range light structures in the Cape Fear River, distributed between its mouth and Wilmington and exposed to water of ocean salinity, diminishing to fresh water at a point below Wilmington. The substructures consist each of four reinforced concrete piles, supporting a tower foundation of four reinforced concrete beams, strengthened at their juncture by reinforced concrete braces, and were built at the same time and with the same materials under the following specifications:

> "PILES.—The four reinforced concrete piles are to be 14 inches square throughout their length with corners chamfered 2 inches, except at the lower end, where the piles are to be tapered for a distance of 10 feet to an 8-inch square end.
>
> "Each pile is reinforced with four 1-inch and four ½-inch round steel rods running the entire length of the pile, with the exception that the ½-inch rods are to be stopped off where the pile starts to taper. The 1-inch rods must be bound together with ¼-inch round steel hoops, having a close loop around each rod and being spaced 2 feet apart throughout the length of the pile; also, 1½-inch iron jet pipe shall be run through center of pile the entire length, as shown.
>
> "BEAMS—The four concrete beams will be reinforced with three 1-inch round steel rods, placed not less than one inch from the lower surface and with one ¾-inch round steel rod in the center, and not less than one inch from the top surface. The beam reinforcement will be 2 inches shorter than the width of the structure.
>
> "CONCRETE—The concrete is to be mixed in the proportion of 1:2:4, using the best grade of Portland cement, clean, sharp, coarse sand and ¾-inch crushed granite. Each pile must be cast in one operation and carefully tamped, and the forms must not be removed in less than 24 hours.

The pile must be wet every day for 2 weeks after the forms are removed and must be 2 months old before they are driven.

"ERECTION—The piles are to be jetted or driven in place with their heads exactly in the same horizontal plane and spaced as shown on drawings. In case the water jet is used, the water must be shut off and the last 12 inches driven by hammer properly cushioned.

"The beams and braces must be cast in one operation, and the side forms must be allowed to remain in place for at least 24 hours; bottom for two weeks. At the end of that time the superstructure may be erected."

Concerning the present condition of these structures, H. L. Beck, superintendent, 6th District, Lighthouse Service, reports under date of October 10, 1922, as follows:

"The structures are inspected at least once a year. Several very careful inspections have been made, after which reports were submitted to the Bureau of Lighthouses in Washington. In 1914 no deterioration was noted. On February 4, 1916, the following report was made: 'No deterioration of the piles and concrete foundation has been noted to date. About half of these structures are in fresh water under favorable conditions for their preservation. The characteristic method of deterioration noted in some other structures in the district, namely, the cracking of the piles and beams along the reinforcement, has not become apparent in any of the Cape Fear structures to date.' "

"In June, 1917, the inspection reports indicated in general that the structures in the lower part of the river were more or less cracked in the piles and under surfaces of the sills, while those in the upper part of the river were in good condition. The cracks in the piles apparently did not extend below the water line and were usually on the chamfers of the piles or on the faces close to the chamfers and about over the main reinforcement. Several piles were scraped of marine growth to see if the cracks extended below the water level. The cracks in the under side of the sills were usually over the main reinforcement, and in some cases appeared as about to flake off. There were practically no cracks on the upper sides of the sills."

"I have inspected a number of the structures within the past year, but made no detailed record of their condition. In general, those in the fresh water of the upper river are still practically as good as when erected where they have not been damaged by collision or ice. As one goes down the river, the cracks are fine where the water is only slightly salt, but they become wider and more serious where the practically undiluted sea water has access to the structures near the mouth. Here the reinforcing rods are exposed and rusted away in places. Pieces of concrete have cracked off in places."

"Deterioration is slowly progressing, being confined in general to corrosion cracks. These concrete substructures are still amply strong to support the skeleton steel superstructures."

"When demolished structures (two destroyed by collision and one by ice in the winter of 1917-18) were rebuilt, creosoted piles were used in preference to reinforced concrete piles. The reasons for the change to creosoted pine piles were: (a) lower first cost, (b) quicker erection, (c) better ability to withstand the shock of collision when struck by floating objects, including vessels navigating the river, and (d) sufficient durability to meet requirements."

Conclusions

Marine borer attack at Beaufort is heavy, and the animals may be expected to be active from May 1 to December 1. Structures erected after December 1 and before May 1 will not be seriously attacked before the latter date.

The service given by the reinforced concrete piles in the structures of the Bureau of Lighthouses in the Cape Fear River illustrates clearly the difference in the effect of fresh and salt water on reinforced concrete.

All wooden structures at Beaufort and near the mouth of the Cape Fear River should be protected against borers if a life of over one year is desired.

CHARLESTON HARBOR

Description

The entrance to Charleston Harbor (Fig. 90), is between two converging jetties which extend nearly three miles seaward across the bar through which there was, in 1921, a straight channel of 30 or more feet at low water, with a least width of 400 feet. The city of Charleston is situated at the head of the harbor and at the confluence of the Cooper and Ashley Rivers, about 7½ miles from the ocean. The principal wharves are on the west bank of the Cooper River, which forms the eastern waterfront of the city. There is an available depth of 30 feet for about 9 miles up the Cooper River to the port terminal, a point three miles above the Navy Yard. In the Ashley River there is a channel of 20 feet depth and 100 feet minimum width as far as Duck Island, at which point the depth decreases to 7 feet at mean low water. The mean range of tide at Fort Sumpter is 5.2 feet, and at the Navy Yard, 5.1 feet. The maximum observed velocities of the tidal current at ebb strength are about 2.6 knots between the jetties; 3 knots between Fort Sumpter and Fort Moultrie; 2 knots off the eastern front of Charleston and 4 knots at the Navy Yard.

Marine Borers

Past History—Both shipworms and crustacean borers are present in these waters. Practically all reports agree that unprotected timber lasts normally about two years, and is therefore employed only for temporary structures, and for fender systems and dolphins where it appears that mechanical injury is likely to anticipate destruction by borers.

Committee Investigations—In order to make proper identifications of the different kinds of borers and to ascertain the rate of destruction and period of immunity if there were such, standard test boards were installed as follows:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Fort Sumpter	A-13	Army	Sept. 6, 1922	4.0	11.0
Standard Oil Refinery	SO-5	Standard Oil Co.	Nov. 1, 1922	......	......
Southern Railway Docks	S-3	Southern Railway Co.	Oct. 1, 1922	0.0	16.0
U. S. Navy Yard	YD-601	Navy	Sept. 1, 1922	6.2	26.9

The results of the examination of the test blocks are as follows:

A-13—The first block, removed September 16, showed a few specimens of *Limnoria* and several hundred minute specimens of *Bankia gouldi;* the next block, removed October 2, was half filled, the longest animal being 4 inches long, and the next block, removed October 23, was completely honeycombed. *Teredo navalis* was also found in small numbers, the largest found up to January 15, 1923, being 5 inches long. A very few specimens of *Martesia* were also found. The board was replaced by a new one on February 16, 1923, and this board was lost and replaced in July. This last board was examined in October, 1923. It is evident that the decline in the activity of *Bankia gouldi* begins about September 15 and has entirely

stopped between November 1 and 15, but the beginning of the breeding season was not definitely determined on account of the loss of the board. *Limnoria* was destructive. The associated organisms were *Balanus*, Bryozoa and Algae.

SO-5—The first *Bankia gouldi* appeared in block 7, removed February 15, 1923, and some specimens had reached a length of $1\frac{1}{2}$ inch by March 15. The first *Teredo bartschi* appeared in the block removed May 15, which contained also two specimens of *Bankia gouldi* with lengths of 4 inches. This number was doubled by July 15, and the block of August 15 was entirely filled. The number of *Bankia gouldi* found was small until the period between June 15 and July 1, and the proportion of *Teredo bartschi* was small.

Limnoria was present in considerable numbers. The associated organisms were *Balanus*, Bryozoa (*Lepralia* and *Bugula*), and Algae.

S-3—The first *Bankia gouldi* and *Teredo navalis* appeared on the block removed November 17. The block removed January 31, 1923, contained about 50 shipworms, the largest of which was a specimen of *Bankia gouldi* nearly 5 inches long. The first *Teredo bartschi* was found May 1, and the block removed June 1 was completely filled with *Teredo bartschi*, indicating that its season of activity which commenced about May 1 was over before the board was placed. Later blocks were entirely destroyed.

Limnoria attack was heavy. Associated organisms were *Balanus* and Bryozoa.

YD-601—The second block, removed October 2, contained four specimens of *Bankia gouldi*, one of them 1 inch long. This number increased to 20 on the next block, and remained about constant until December 6, when about 50 were found, the length being up to 4 inches. A few specimens of *Teredo navalis* also appeared. On January 6 five specimens of *Teredo bartschi* with a length of from 1 inch to 2 inches were found, in addition to the other species. Block 11, removed February 22, contained about 100 shipworms of the three species. The board was replaced at this time by one of the 1923 model. The first shipworms (*Bankia gouldi*) appeared with a maximum length of about 2 inches in the block removed July 5. This length had increased to about 5 inches by August 2, at which time *Teredo navalis* of the same length was found. The maximum length one month later was over 11 inches. *Teredo bartschi* was present in small numbers.

There was a fairly heavy attack of *Limnoria;* associated organisms were *Balanus*, Bryozoa and Algae.

Salinity and temperature observations were recorded monthly by the Navy at YD-601. The results are shown on Fig. 91.

Field Tests—An exhaustive test to determine the value of copper wire and strips was made by the U. S. District Engineer and will be found reported in Chapter II, page 11.

A similar test of iron wire and strips was made by the Seaboard Air Line, the results of which will be reported later.

Methods of Protection

Creosote Impregnation—This method of protection is quite generally employed with varying results. Pine piles supporting the Charleston Lighthouse Depot, treated with 18 pounds of creosote per cubic foot in the piles and 14 pounds in the braces, driven in 1916, showed no damage until

1920. An inspection made July 3, 1922, disclosed serious damage to the bracing by *Limnoria*. The Superintendent of the 6th District says: "The creosoted piles have not been seriously damaged so far, but a good many of them have been attacked. In some cases there are areas as large as 3 or 4 square feet that have been attacked by *Limnoria*, but the borings do not go into the piles more than 1/4 inch. In smaller areas the attack has gone deeper."

The Navy has experienced both good and bad results with creosote treatment, one lot of piles which were driven in 1911 having been found unserviceable in 1914. Piles with 18 pounds' treatment driven in the Southern Railway Company's coal pier in 1914-1915 were found in 1922 to have been severely attacked, and piles with 22 pounds' treatment in the Clyde Line docks driven in 1912 were being attacked in 1922, with a prospective service of only two more years.

The dry dock pontoons of the Charleston Dry Dock and Machine Co. were sheathed in 1919 with a layer of ship felt covered by 1-inch creosoted lumber, 12 pounds' treatment. All sections of the dock have been inspected during 1923, and the sheathing found to be in practically the same condition as when applied.

Armor—Both copper and yellow metal have been used as sheathing, proving effective as long as intact.

The Charleston Dry Dock & Machine Company drove about 600 yellow pine piles for their dock at Charleston, S. C., in the fall of 1918. These piles were studded with roofing nails 1 inch long with 3/8-inch heads, the spacing being obtained by using 1/2-inch mesh chicken wire as a template. The nails were driven by negro boys at from 10 to 15 cents per hour. The cost, including the material, ran about 40 cents per linear foot, of which about 22 cents was labor. A photograph of a section of timber cut from one of the piles so treated, and pulled in September, 1922, is shown in Fig. 22, page 102. Under the microscope this specimen shows evidence of having been penetrated by 15 shipworms. On the edges four burrows are exposed. The invasion was apparently stopped by the repellent qualities of the spreading iron rust.

Untreated piling in these waters lasts not to exceed two years.

A protective coating has been successfully tried out at the U. S. Navy Yard in the construction of building ways. Immediately after the piles were placed, 20 d nails were driven in here and there about ten inches on centers, and a sheet metal casing placed about the piles allowing about two or two and one-half inch clearance around the circumference and carried down to approximately 12 inches below the mud line. This space was then filled in with 1:2:4 concrete with 5 per cent hydrated lime. The only failures were those in which the concreting was not carried deep enough into the mud.

Substitutes for Timber

Metal—There is a cast iron pile wharf at Sullivans Island in front of old Fort Moultrie, which was constructed in 1907 and is still in good condition. No special record of this wharf has been kept. One or two of the brace piles at the end of the wharf have given way, due to rusting of the flange bolts.

Concrete—No data on concrete have been collected.

FIG. 90


MAP SHOWING LOCATION OF
TEST BOARDS
CHARLESTON HARBOR
SOUTH CAROLINA
1923
NAUTICAL MILES
YARDS
1,000
500
0
1,000
2,000
A-13
A-13-1 TO 8
SA-4
S-3
SO-5
YD-601
NAVY
YARD
COOPER RIVER
ASHLEY RIVER
CHARLESTON
N

19
bı
cr
th
sq
in
de

m
se
R.
se
dc
of

sh
12
19
w

pı

pi
pi
sp
T
cc
al
oı
2:
be
T
ir

Y
w
ce
oı
d
fi
u
th

S

ol
d
b
fl

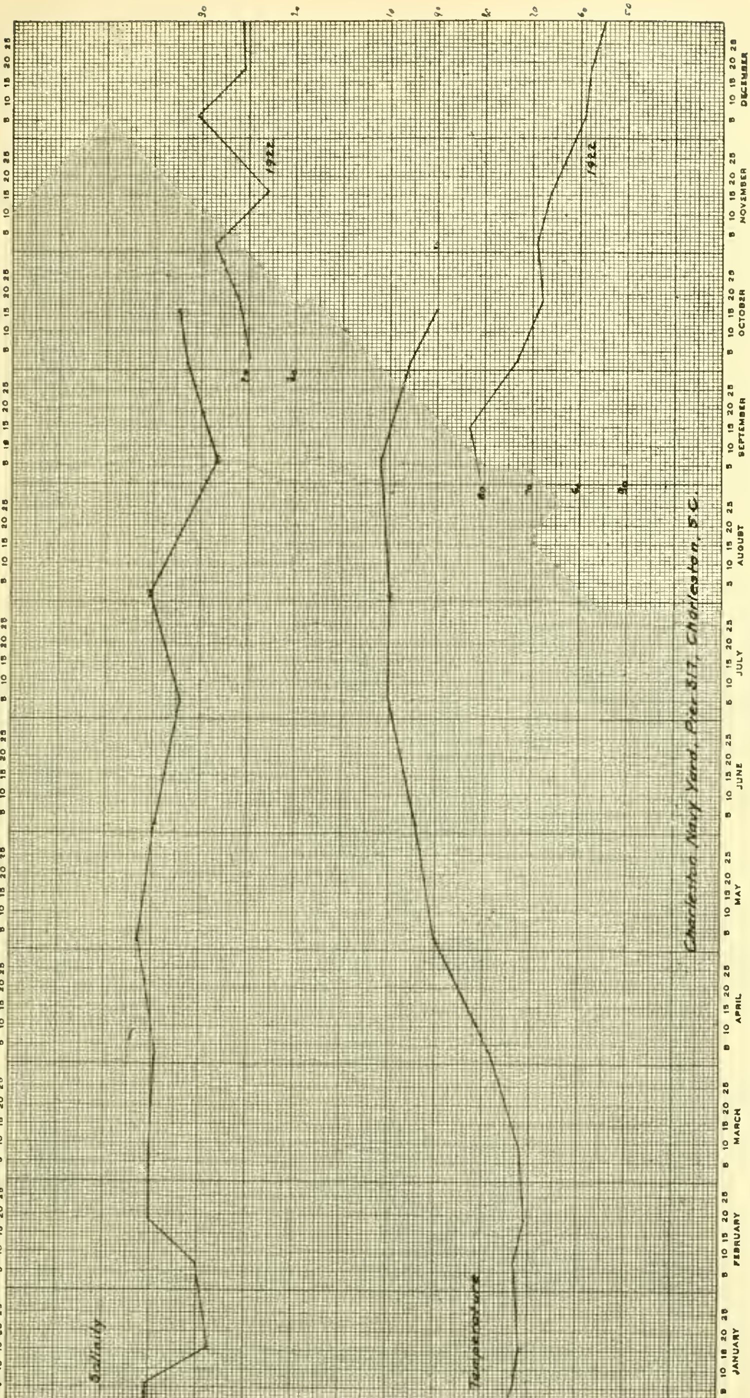


Fig. 91—Salinity and Temperature Observations, Navy Yard Pier 317, Charleston, S. C.

Conclusions

The period of inactivity so far as the growth of the animals is concerned is less clearly defined than in other harbors. It appears that while some growth occurs during the winter, the period of comparative inactivity extends from about the 15th of November to about May 1.

Timber piles require the best possible protection in order to avoid heavy losses—20 to 22 pounds creosote impregnation can be expected to give an average life of about 10 to 12 years.

The wharf of the Charleston Dry Dock and Machine Company indicates the possibility of its method of protection giving long life, based on the results of the first five years, since the iron impregnation will increase in depth with time and therefore become more effective. It would be advisable in using this method to drive the piles early in the period of inactivity of the borers (November or December) so that the rust incrustation may be as heavy as possible before the borers become active in the spring. These piles should not be allowed to dry out and check before being driven.

Sufficient time has not yet elapsed since the construction of this dock to show definitely its service life, but its present condition indicates that this process has much promise.

SAVANNAH AND BRUNSWICK

General Description

From the entrance to the Savannah River (Fig. 92), about 15 miles below the City of Savannah, the river is being improved to obtain a depth of 30 feet with a general width of 500 feet to the Quarantine Station; thence 26 feet depth and 400 feet width to the Seaboard Air Line Railway Bridge; and thence a depth of 21 feet and width of 300 feet to Kings Island, a total distance of 24 miles. In 1921 there was a minimum depth of 21 feet from the sea to the City. The mean velocity of the ebb current at strength ranges from 1.1 knots at Savannah to 2¾ knots per hour at the entrance to the river, and that of the flood is about ½ knot at Savannah and 2 knots at the entrance. The mean rise and fall of tide at Fort Scriven is 6.9 feet and at Fort Jackson 6.6 feet.

The average distance from the terminals of the various railway and steamship companies at Brunswick (Fig. 93) to the open sea is about 12 miles, with a controlling depth of 30 feet at mean high water. The tidal range at the entrance bar is 6.6 feet and within the harbor 7.0 feet. The tidal currents have an estimated velocity of one to two knots per hour.

Marine Borers

Past History—At the City of Savannah, the water is said to be fresh and there is no record of the presence of marine borers. Near the mouth of the Savannah River and in Brunswick harbor proper, both *Limnoria lignorum* and shipworms are present. The life of unprotected timber is estimated from past experience to be generally not over 2 years.

Committee Investigations—The Savannah River appeared to offer ideal territory for determining the boundary line beyond which marine borers would not thrive. Accordingly nine boards were installed at fairly regular intervals from the mouth of the river at Fort Scriven to the Central of Georgia Railway terminals. It was the plan of the Committee to study the physical and chemical condition of the water on either side of the point of

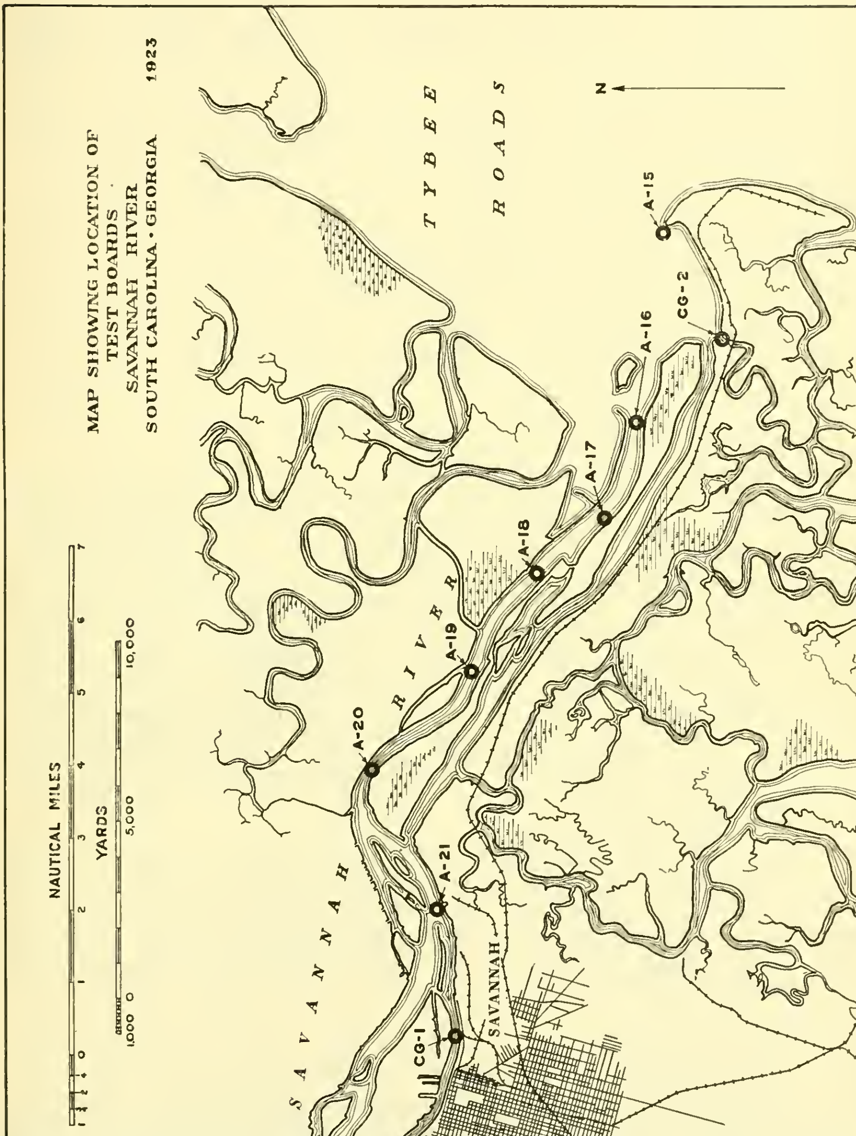

MAP SHOWING LOCATION OF
TEST BOARDS
SAVANNAH RIVER
SOUTH CAROLINA · GEORGIA 1923
NAUTICAL MILES
YARDS
1,000 0 5,000 10,000
TYBEE
ROADS
N
SAVANNAH RIVER
SAVANNAH
A-15
CG-2
A-16
A-17
A-18
A-19
A-20
A-21
CG-1

Fig. 92

farthest advance when it had been definitely determined at the end of the present season. Boards installed in both Savannah and Brunswick harbors appear in the following list:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Savannah River—					
Fort Scriven	A-15	Army	Sept. 15, 1922	1.5	7.5
Lazaretto Creek—Central of Ga. Ry. Crossing	CG-2	Central of Ga. Ry.	Sept. 15, 1922	2.0	10.0
Quarantine Dock	A-16	Army	Sept. 15, 1922	4.5	9.5
Long Island Crossing	A-17	Army	Sept. 15, 1922	1.0	*3.1
Lower Dolphin	A-18	Army	Sept. 15, 1922	2.8	9.6
Girls House	A-19	Army	Sept. 15, 1922	0.8	9.6
Upper Dolphin	A-20	Army	Sept. 15, 1922	1.8	13.8
Fort Jackson	A-21	Army	Sept. 15, 1922	4.4	8.4
Berth No. 8—Cent. of Ga. Railway Terminal	CG-1	Central of Ga. Ry.	Sept. 15, 1922	9.0	11.0
Brunswick Harbor—					
A. B. & A. Ry. Terminal	ABA-1	A. B. & A. Ry	Aug. 1, 1922	2.0	10.0
A. C. L. Ry. Terminal	ACL-1 ACL-1a	A. C. L. Ry	Aug. 29, 1922	14.5 8.5	0.5 5.5
Turtle River Docks—Southern Ry. Co	S-4	Southern Ry	Oct. 1, 1922	1.0	0.5

*Board suspended in horizontal position.

The results of the inspection are as follows:

A-15—Block 2, removed October 16, contained several hundred specimens of *Bankia gouldi* and destruction proceeded so rapidly that it became necessary to transfer the blocks to a concrete board, which was done at the time of the removal of the 6th block, December 16. About 1 per cent of the shipworms found was *Teredo navalis*. On March 1, 1923, the remaining original blocks (10-24) and replacement blocks (25-34) were all removed and subjected to a careful examination. Among other results of this examination, the season of activity was determined to have ended between November 1 and November 15 and it was also found that after this date further growth of living shipworms ceased. A new test specimen of 1923 model was installed, the first block of which to show shipworms (*Bankia gouldi*) was No. 4, removed July 12, after having been in the water one month. *Teredo navalis* appeared one month later. Associated organisms were *Balanus* and Bryozoa.

CG-2—Shipworms first appeared in block 2, removed October 16. Succeeding blocks (3-9) contained each from 25 to 100 specimens of *Bankia gouldi* and 2 to 4 of *Teredo navalis*, the rate of destruction being considerably less rapid than at A-15. An examination of the old board and blocks, removed February 15, confirmed the date of the ending of the season of activity determined for A-15. Associated organisms were *Balanus*, *Ostrea* and Bryozoa.

A-16—The test here was in all respects similar to CG-2 with the exception of the absence of *Ostrea* and the presence of Algae.

A-17—The findings on these blocks were similar to those at CG-2, the destruction while quite severe being less than at A-15. The end of the season of activity came abruptly about October 1. A test board of 1923 model was substituted for the old one, March 1, 1923. Six series of blocks from this board have been examined, the last one removed August 30. None of them contained shipworms. Associated organisms were *Balanus* and Algae.

A-18—One specimen of *Bankia gouldi* was found in block 12, removed March 16, 1923. Succeeding blocks (14-25 inclusive) contained each from 3 to 6 specimens attaining a length of 12 inches. Associated organisms were *Balanus* and Algae.

A-19—Twenty-six blocks were examined, none of which contained shipworms. A fairly heavy set of *Balanus* was observed on the majority of the blocks.

A-20—No shipworms were found in any of the 22 blocks examined, and *Balanus* was considerably less numerous than at A-19.

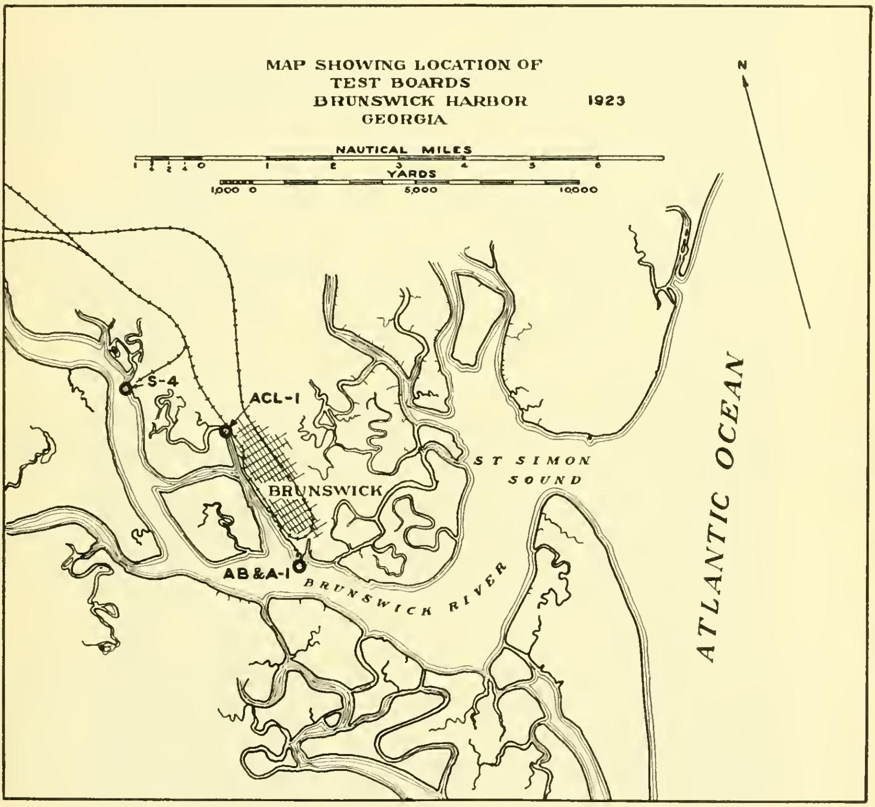


FIG. 93

A-21—With the exception of a few specimens of *Balanus* found on block 3, and a trace of Algae on blocks 6 and 7, no life of any kind was observed on the nine blocks examined.

CG-1—No life of any kind was observed on the seven blocks examined from this board.

From the foregoing it would appear that conditions necessary for the existence of the *Bankia gouldi* have become quite unfavorable when the lower Dolphin (A-18) about 6¾ miles from Fort Scriven has been reached,

and prohibitive between that point and Girls House (A-19) 2¼ miles farther upstream.

Records of salinity and temperature observations made at Brunswick by the Atlanta, Birmingham and Atlantic Railroad and the Southern Railway Company are shown on Figs. 94 and 95.

ABA-1—The destruction at this point was rapid and severe. In addition to great quantities of *Bankia gouldi*, a few specimens of *Teredo navalis* and *Teredo bartschi* were observed. *Limnoria* was noted on some of the blocks, and *Balanus* was usually present. On account of the complete destruction of the test specimen it was impossible to make an examination to determine the date of the ending of the season of activity. The new blocks of revised type, however, fixed the beginning of the 1923 season as occurring between May 1 and June 1.

ACL-1 and 1a—Destruction by *Bankia gouldi* was similar in intensity to ABA-1. A fairly heavy attack of *Limnoria* was also observed. A few specimens of *Teredo bartschi* but none of *Teredo navalis* were found. Associated organisms were *Balanus* and Bryozoa.

S-4—*Bankia gouldi* was first found in block 8, removed February 1, and ranged in number from 5 to 12 in each of the succeeding blocks 9-14 inclusive. Blocks 15 to 19 inclusive contained an average of 30 specimens, and blocks 20, 21 and 23 each one specimen. Block 19 also contained several specimens of *Teredo bartschi*. Associated organisms were *Balanus*, Bryozoa and Algae. *Limnoria* attack was severe.

Methods of Protection

Impregnation with creosote is in general use. The oldest structure of record so protected is the wharf at Fort Scriven, built in 1908. The pine piles in this structure were treated to refusal, and were in good condition when inspected in the summer of 1922.

The records of treatment and service of the piles in the Turtle River docks of the Southern Railway Company are unusually complete. Several analyses of the creosote used have been made and these with the service records will be found in Chapter VI, page 128.

Substitutes for Timber

Concrete—Reinforced concrete bulkheads and piers on precast reinforced concrete piles were built for the Atlanta, Birmingham & Atlantic Railroad terminals at Brunswick in 1907. Unfortunately no construction records are available. The 6 inch sheet piling and the piles supporting the piers show deterioration from low water line to the top. Below low water line good condition prevails. The 18-inch sheet piling shows no signs of failing.

Conclusions

Intense borer attack may be expected in the Savannah River as far up stream as Long Island Crossing from which point it decreases in intensity until it disappears at a point between Lower Dolphin and Girls House. An increase in salinity on account of a protracted period of low rainfall would probably extend the range of the borers somewhat above this point.

The period of inactivity of shipworms extends from about December 1 to June 1 in the Savannah River.

All structures in Brunswick Harbor are subject to heavy attack.

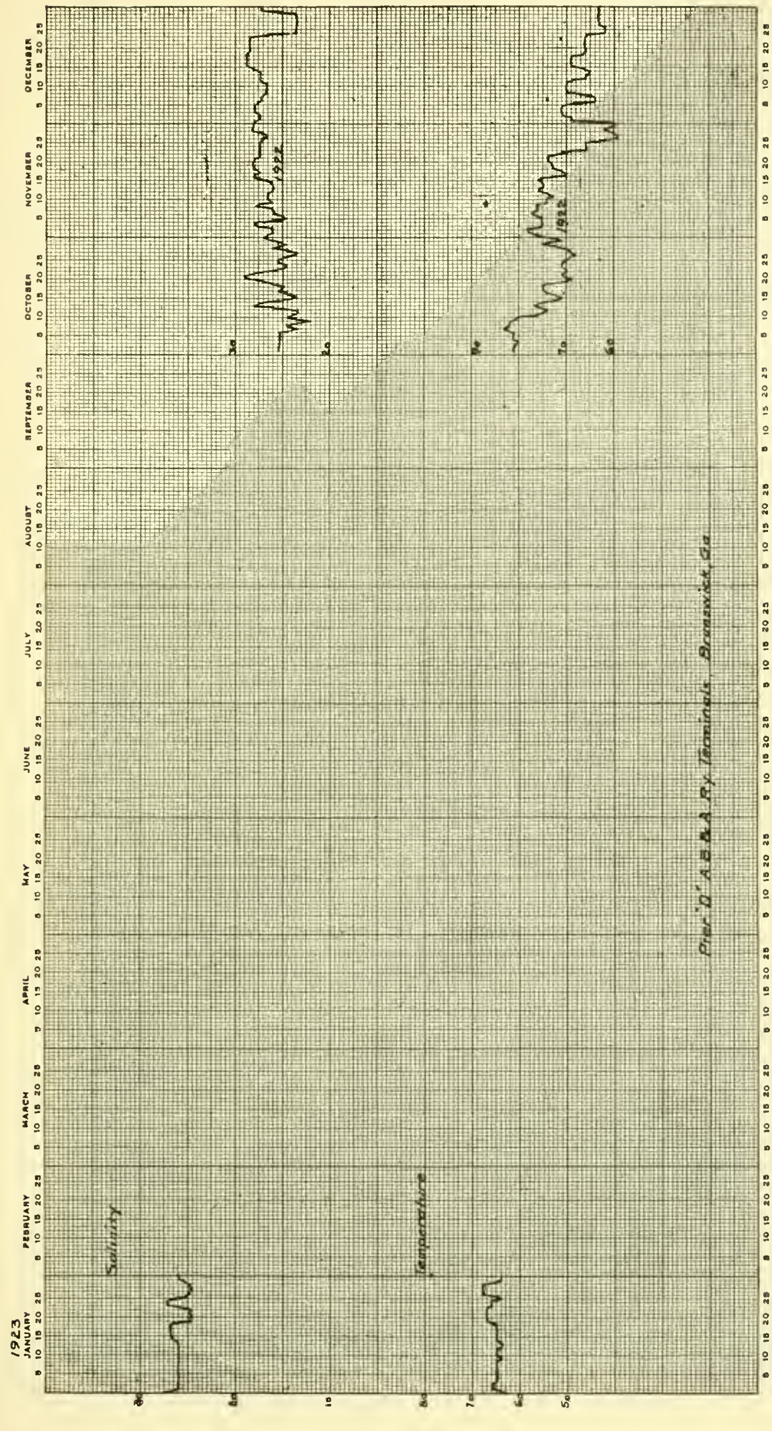


Fig. 94—Salinity and Temperature Observations, A. B. & A. Ry. Co.'s Pier D, Brunswick, Ga.

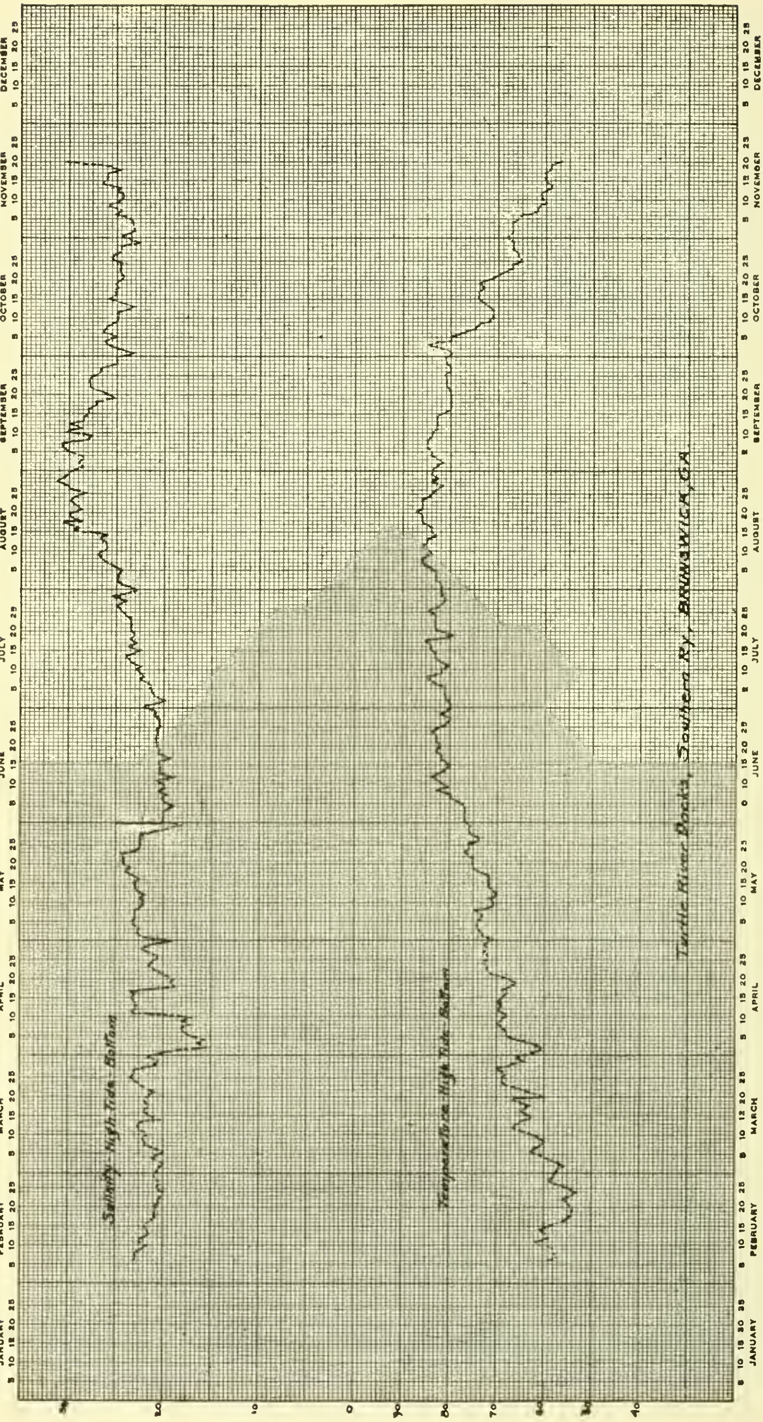


FIG. 95—SALINITY AND TEMPERATURE OBSERVATIONS, SOUTHERN RY. CO.'S TURTLE RIVER DOCKS, BRUNSWICK, GA.

The beginning of the period of activity occurs during the month of May, but the close of the period was not determined. It probably does not differ much from that established for the Savannah River.

All timber piles below Girls House in the Savannah River and all in Brunswick should have the best protection that can be devised.

EASTERN COAST OF FLORIDA

General Description

This report includes the Eastern Coast of Florida from Fernandina (Fig. 96) to Key West, and the St. Johns River from its mouth to Palatka

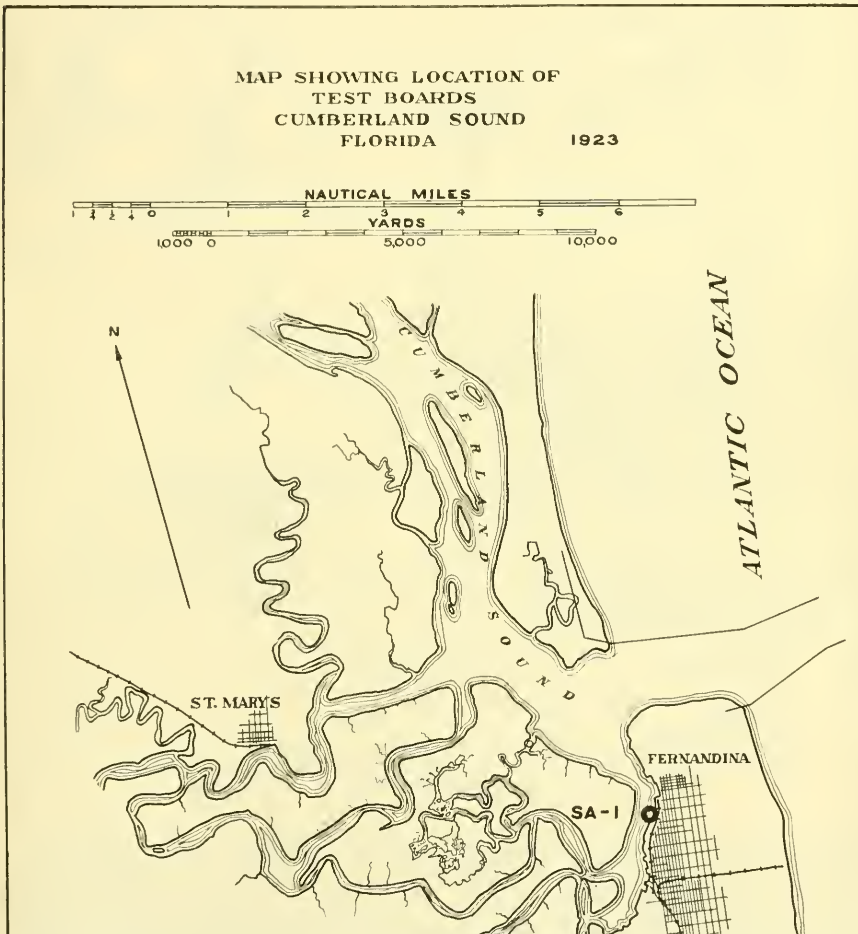


FIG. 96

(Fig. 98). The general character of the coast between Fernandina and Miami is low and sandy, with frequent shoals extending from 3 to 8 miles off shore. From Miami to Key West the coast is formed by a chain of small

islands known as the Florida Keys, outside of and nearly parallel to which are the Florida reefs.

Cumberland Sound is the approach to Fernandina where the Seaboard Air Line has installed a test board at their phosphate dock on the Amelia River in about 28 feet of water. Tidal currents at the entrances to the Sound are of high velocity, reaching at times 5 knots per hour.

Jacksonville (Fig. 97) is located on the St. Johns River 28 miles from its mouth, and Palatka is 54 miles farther upstream. The channel is being improved to a depth of 30 feet from Jacksonville to the sea. It is about 600

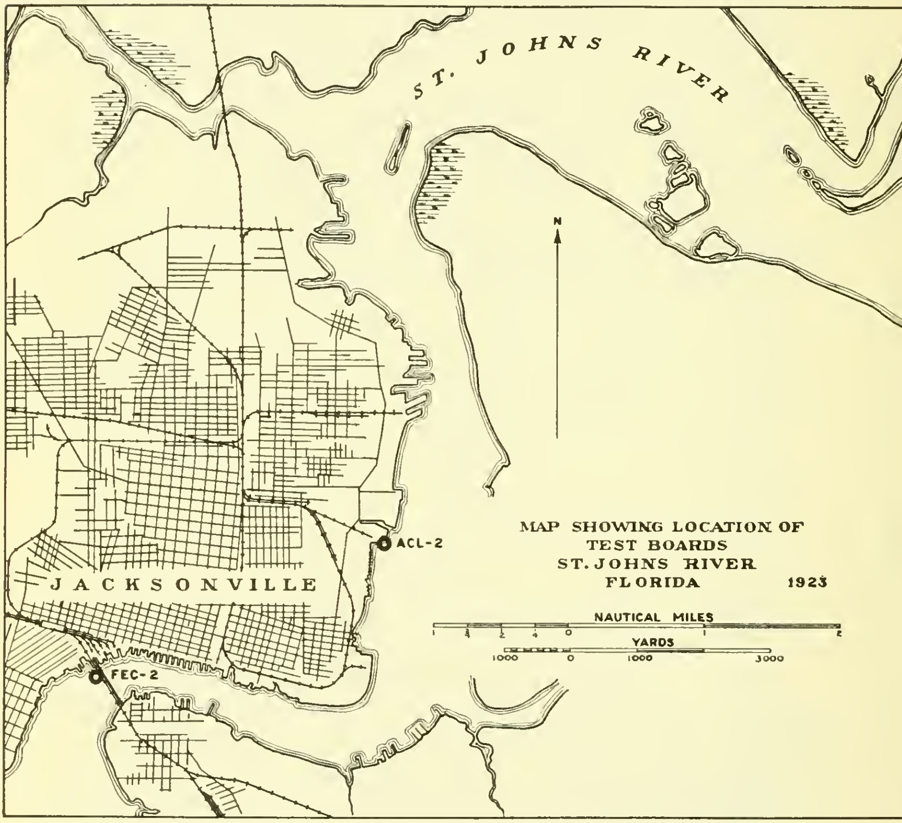


FIG. 97

feet wide across the bar and 500 feet wide to Mayport. From Mayport to Jacksonville the channel width varies from 300 to 600 feet. The mean rise and fall of tide ranges from 5.0 feet at the entrance to the river to 1.0 foot at Jacksonville. The salinity of the water at Jacksonville varies from 2 to 14 parts per 1,000, and the temperature from 70 to 85 degrees Fahr. Above Jacksonville there is a dredged depth of 10½ feet to Palatka (Fig. 98). Infrequent tests of the water at Palatka made by the Florida East Coast Railway have shown no salinity.

Jupiter (Fig. 99), about 80 miles north of Miami, is important to this

investigation as being the northernmost limit of two hitherto unidentified species of *Bankia*.

Miami (Fig. 100), located on the west shore of Biscayne Bay, 10 miles below its head and 8 miles above Cape Florida, has wharves with depths alongside ranging from 4 to 15 feet.

Channel Five (Fig. 101) passes between Lower Matecumbe Key and Long Key about 70 miles east of the City of Key West and 85 miles from Miami.

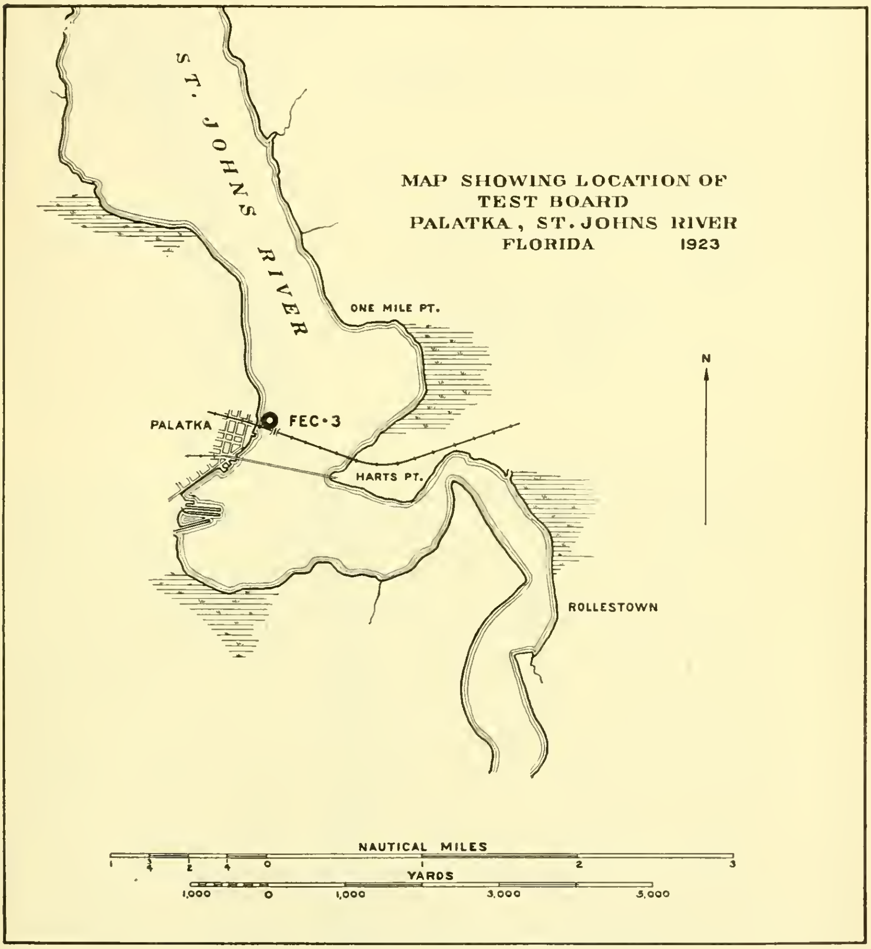


FIG. 98.

Marine Borers

Past History—Shipworms and crustacean borers are known to exist along the entire coast line. *Limnoria* has been reported as far up the St. Johns River as Jacksonville and shipworms have done great damage at that point though they do not attack every year. In 1914 a part of one of the wharves of the Atlantic Coast Line at Jacksonville failed on account of shipworm attack.

Officers of the Corps of Engineers estimate the life of unprotected timber at the mouth of the St. Johns River and at Miami at 4 years and 6 years at Jacksonville. *Sphaeroma* is present in considerable numbers at Jacksonville and Palatka. This borer cut off and totally destroyed large piles in a structure belonging to the Florida East Coast Railway at the latter point in less than 17 years.

Committee Investigations—Standard test boards were placed as follows:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Fernandina—S. A. L. Phosphate Dock	SAL-1	Seaboard Air Line	Sept. 14, 1922	0.8	7.0
Jacksonville—A. C. L. Warehouse Dock Export Terminals	ACL-2	Atlantic Coast Line	Aug. 25, 1922	......	......
Jacksonville—F. E. C. St. Johns River Bridge	FEC-2	Florida East Coast Railway	July 1, 1922	0.2	6.0
Palatka—F. E. C. Bridge	FEC-3	Florida East Coast Railway	July 1, 1922	0	6.5
Pablo Creek (Fig. 102)	FEC-1	Florida East Coast Railway	July 1, 1922	0	2.0
Jupiter	FEC-4	Florida East Coast Railway	July 1, 1922	0	7.0
Miami	FEC-5	Florida East Coast Railway	July 1, 1922	0	7.0
Channel Five	FEC-6	Florida East Coast Railway	July 1, 1922	1.2	4.2

The inspection of test blocks gave the following results:

SA-1—The first block, removed after 16 days' immersion, showed 6 shipworm larvæ, while the third block one month later showed about 20 specimens of *Bankia gouldi* up to 2 inches in length and one of *Teredo bartschi* 1 inch long. The fourth block, removed November 15, contained several specimens of *Teredo bartschi* with larvæ ready to be ejected, while the number of *Bankia gouldi* in the December 4 block was over 200. The ninth block, removed February 1, 1923, was completely filled with *Bankia gouldi* varying in length from a few millimeters to 6 inches; some individuals of *Teredo navalis* were also found. This board was replaced about March 1 by a 1923 model board. The first block, removed April 6, showed one *Bankia gouldi* 1 mm. long. *Teredo bartschi* 1 to 3 mm. long appeared on the blocks removed June 4. The specimens of *Bankia gouldi* in the July block, immersed 4 months, were 4 inches long and those of *Teredo bartschi* about 2½ inches, while the block with one month's immersion contained over 200 shipworms about evenly divided between the two species, the longest measuring 2½ inches. The attack on the July block was about the same and in the 5 months block *Teredo navalis* about 3½ inches long was measured. The shingle block immersed between March 1 and October 15 was filled with shipworms, principally *Bankia gouldi*, one of which had a length of 13 inches.

The *Limnoria* attack was extremely heavy. The associated organisms were *Balanus*, Bryozoa and some Algae.

ACL-2 and FEC-2—No borers were found in blocks from either of these boards. Associated organisms were *Balanus*, *Mytilus* and Green Algae.

FEC-3—No life of any kind except a little vegetation appeared on any

of the blocks but a pile section received from another structure had been cut off by and was filled with *Sphaeroma.*

FEC-1—No borers excepting two specimens of *Sphaeroma* were found but the growth of *Balanus,* Bryozoa and *Mytilus* was very heavy indicating the possibility of shipworm attack.

FEC-4—The first shipworm, *Bankia sp. I,* appeared in the seventh block,

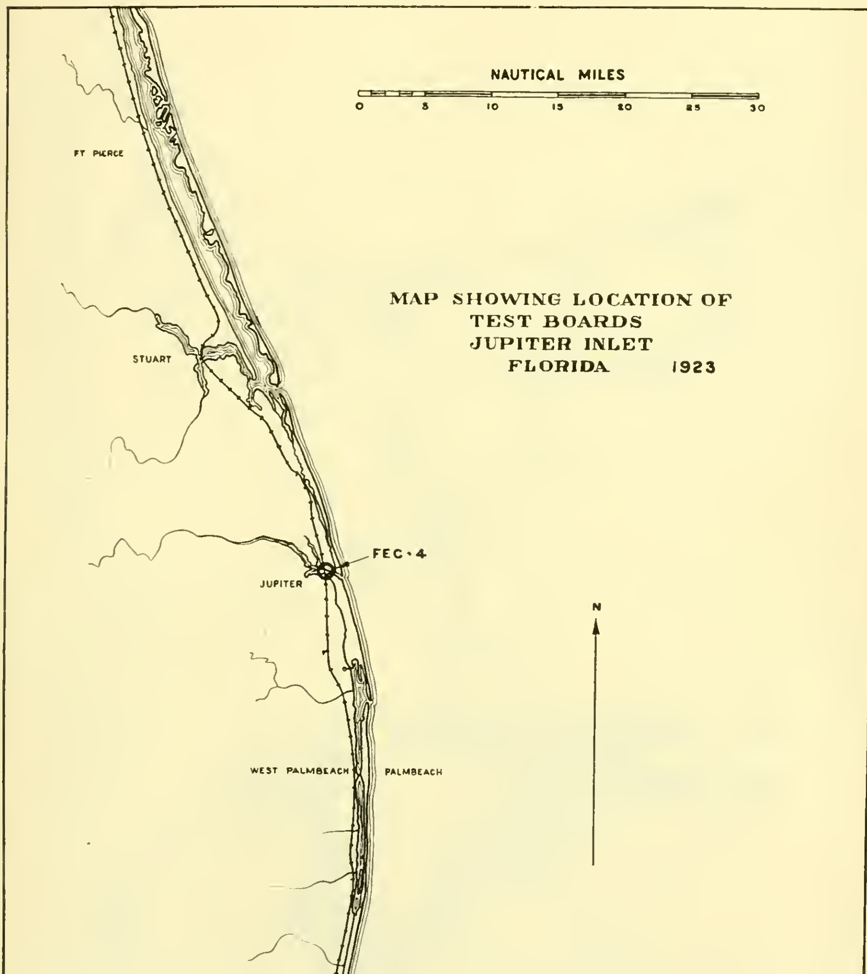


FIG. 99

removed October 15. The next block also contained one specimen. No more were found until the block removed February 28, 1923, in which there were 3 animals from 5 mm. to 10 mm. long. The board was lost and replaced April 1. No shipworms were found until block 4, removed May 31, which contained 6 specimens of *Bankia sp. I* from 2 mm. to 8 mm. Block 5 contained over 100 specimens, some of them 4 inches long. A specimen

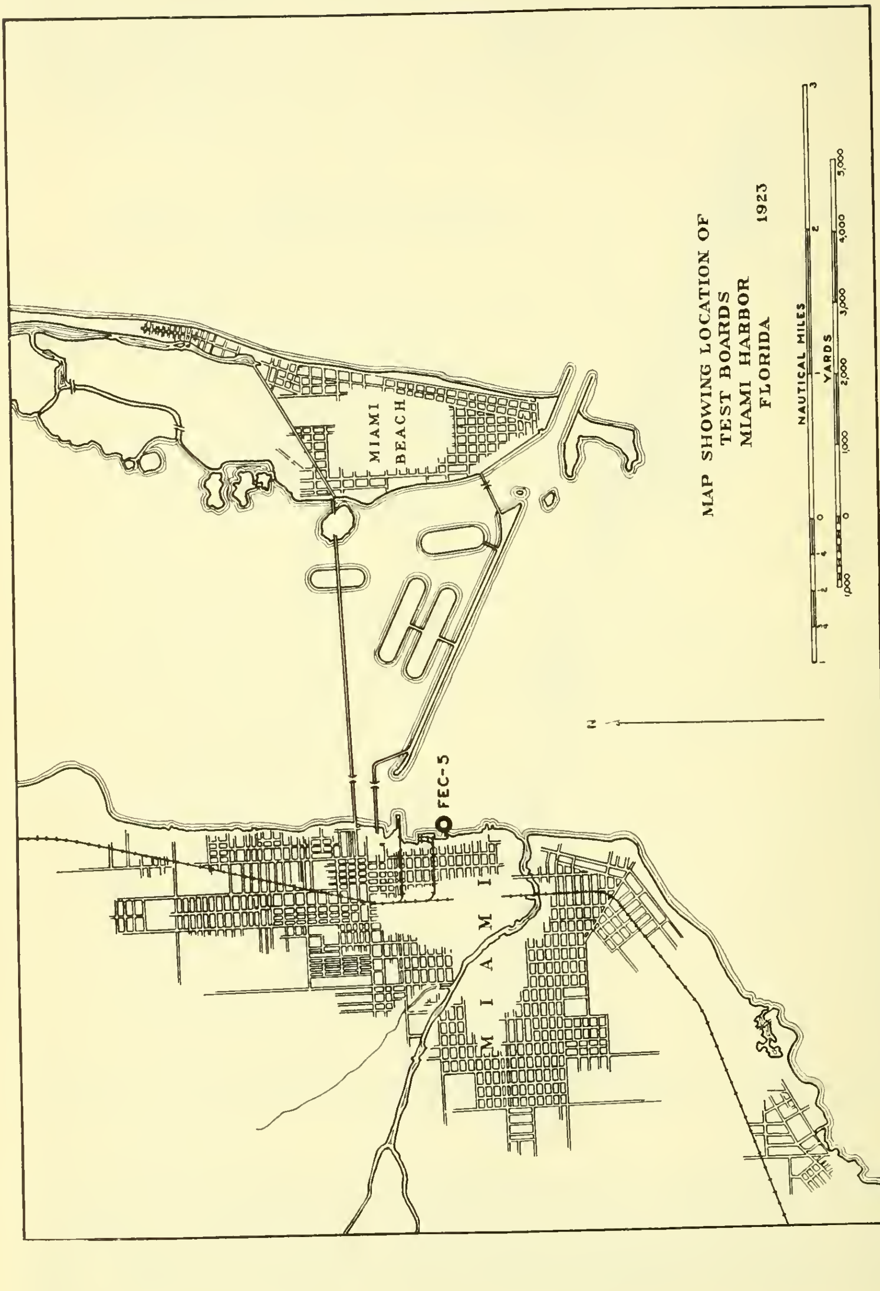

MAP SHOWING LOCATION OF
TEST BOARDS
MIAMI HARBOR
FLORIDA
1923
MIAMI
BEACH
MIAMI
FEC-5
NAUTICAL MILES
YARDS

Fig. 100

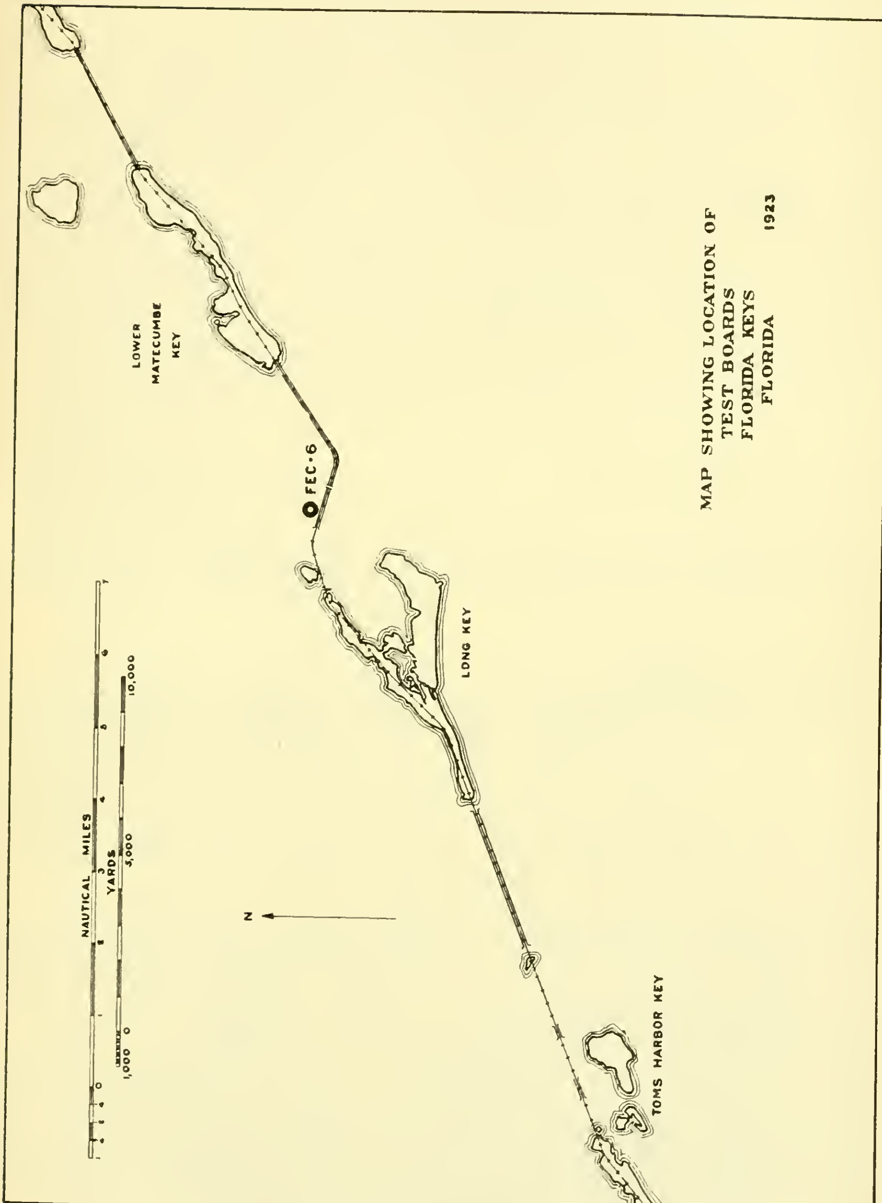

MAP SHOWING LOCATION OF
TEST BOARDS
FLORIDA KEYS
FLORIDA
1923
LOWER MATECUMBE KEY
FEC-6
LONG KEY
TOMS HARBOR KEY
NAUTICAL MILES
YARDS
N

FIG. 101

of *Bankia sp. C* was also found. Later blocks were completely honeycombed. One specimen of *Martesia* and a few of *Sphaeroma* were also found. The associated organisms were *Balanus*, Bryozoa, *Ostrea* and Algae.

FEC-5—Very little life was found on this board, only one shipworm, *Bankia sp. I,* and a few specimens of *Balanus*.

FEC-6—The first shipworms and *Limnoria* appeared on the second block, removed August 1. The blocks until October 15 continued to show a few larval shipworms which did not seem to prosper but the seventh block, removed on this date, contained a specimen of *Teredo thompsoni* 3/8 inch long and one of *Teredo sp. D* 2 inches long. Block 14, removed January 31, 1923, contained *Teredo clappi* and *Teredo* (*Lyrodus*) *bipartita* of small size and few in number and the next block in addition to other specimens contained a specimen of *Teredo bipartita* only 3/4 inch long but containing embryos. The next block contained in addition to the other species several specimens of *Teredo somersi,* only 7 mm. long, but containing embryos. The board was replaced by a 1923 model board on March 1 but while embryos were found on most blocks little growth occurred until July 18 when the block contained about 100 specimens of *Teredo clappi,* some of them 2 inches long. The growth and number of animals continued through the summer, but up to September 18 no species other than *Teredo clappi* had appeared in the new board.

The *Limnoria* attack was very heavy at times reaching a depth of 1/2 inch and killing the shipworms. Other organisms were *Balanus* and Bryozoa.

Salinity and temperature observations of the water of St. Johns River at Jacksonville were made by the Atlantic Coast Line Railway. These records are shown on Fig. 103.

Methods of Protection

Creosote Impregnation—This method of protection is perhaps the most generally used in this territory, but cannot be said in the light of past experience to be entirely satisfactory. According to the Army, the life of piles treated with approximately 22 pounds of creosote per cubic foot has averaged about 12 years. The Lighthouse Service has recently adopted this method of protection, and specifies impregnation to refusal (22 to 24 pounds). However, a slight attack was found within 14 months on piles so treated and driven in Miami harbor March 7, 1921.

Armor—Terra cotta pipe placed around the piles extending from below the mud line to above highwater, the annular space being filled with sand or concrete, has been employed as a protection. This practice, in vogue some twenty years ago, did not prove generally satisfactory on account of the large amount of breakage, and is no longer employed.

The Lighthouse Service has two structures in this territory in which the piles are armored with standard cast iron bell and spigot pipe. These structures are the Biscayne Channel Light No. 34, and the Mosquito Bank Light at Hawk Channel, and are square pyramidal wooden structures, each on four untreated pine piles. The former was built in 1903, and the latter in 1901. They are reported to have been in good condition in 1922, except for the decay of the tops of the piles above the casings.

Substitutes for Timber

Wrought Iron piles have been used in structures on Florida reefs since

1852. A report by the Superintendent of Lighthouses, 7th District, follows:

"In regard to wrought iron structures, these are pyramidal skeleton structures on piles; columns and struts are round solid wrought iron, all well braced with round wrought iron tension rods. Columns, piles and struts are connected by cast iron sockets with lugs, and wrought iron pins. Floor plates, parapet plates, roof, etc., are of cast iron."

"At the Florida Reef Light Stations these large structures are scaled and painted by the keepers, who also keep watch at night, besides keeping station clean, cooking, etc. Most of the time there are only two keepers at these stations. After they have got the station in good condition it is an easy matter for one man to keep it so."

"If wrought iron structures are given the proper attention and are painted periodically with suitable paint before paint has time to wear off, say once every 2 or 3 years, structure will require only painting, with small amount of scaling in spots. But if allowed to deteriorate the cost of maintenance increases tenfold."

"The wrought iron piles and tension rods that are in the water and where the sea washes daily are never scaled or painted and the tension rods in the water have to be renewed in about 15 to 20 years, usually because they wear away at the point of intersection. The wrought iron piles appear to be protected by the rust film or scale, as they show very little deterioration after years of service—69 years in one instance in this district."

Concrete—Several old concrete structures on the Florida Coast have been inspected and reported on by the U. S. District Engineer at Jacksonville as follows:

"In accordance with instructions contained in letter from the Office of the Division Engineer on the above subject, dated July 26, 1923, report is submitted on cement constructions at St. Augustine, Fort Marion and Fort Taylor, and in addition, on similar constructions on the St. Johns River jetties."

"Except for the concrete capping of the groins constructed at St. Augustine in the years 1889 and 1890, it has not been possible to discover any records of the materials used in the various works or complete descriptions of the methods of construction. Particular attention has been given, therefore, to the concrete used in the groin capping, and the report thereon is as complete as possible."

St. Augustine.—"Altogether, nine groins were constructed for the protection of north beach and the north point of Anastasia Island at the entrance to St. Augustine Harbor. The groins located on north point are at present, and have been for a number of years, practically buried in sand to some depth so that a thorough inspection of their present condition is not feasible. Furthermore, since these groins have been protected from the sea action for a number of years, it is thought that an inspection of their present condition would not be as enlightening as an inspection of the Anastasia Island groins, which have been exposed to the elements throughout their existence."

"Work on groin No. 1, Anastasia Island, began October 1, 1889, and ended June 30, 1890. This groin was constructed 341 feet long, the materials used being brush fascines, riprap stone and oyster shells, with concrete capping. The latter consisted of concrete blocks 24 to 30 inches thick, 5 feet long and 6 feet wide at the base, with a 2 foot crest and side slopes one on two. In order to prevent the travel of the riprap along the groin, each third capping block was made 4 feet long and 8 feet wide at the base. Nine-tenths of the work on this groin was done with the Anchor Brand of Portland cement, mixed 1 part cement, 4 parts beach sand, and 6½ parts coquina gravel; and the F. O. Norton Brand of Rosendale cement, mixed 1 part beach sand, and 2⅔ parts of coquina gravel. A small amount of work was done with Sphinx and Dyckerhoff Brands of Portland cement, mixed 1, 4, 6½; Fisher's U.S.G. Rosendale, mixed 1, 2, 4; and Hydraulic Lime of Teil, mixed 1, 2, 4. The records do not indicate in what portions of the groins the various

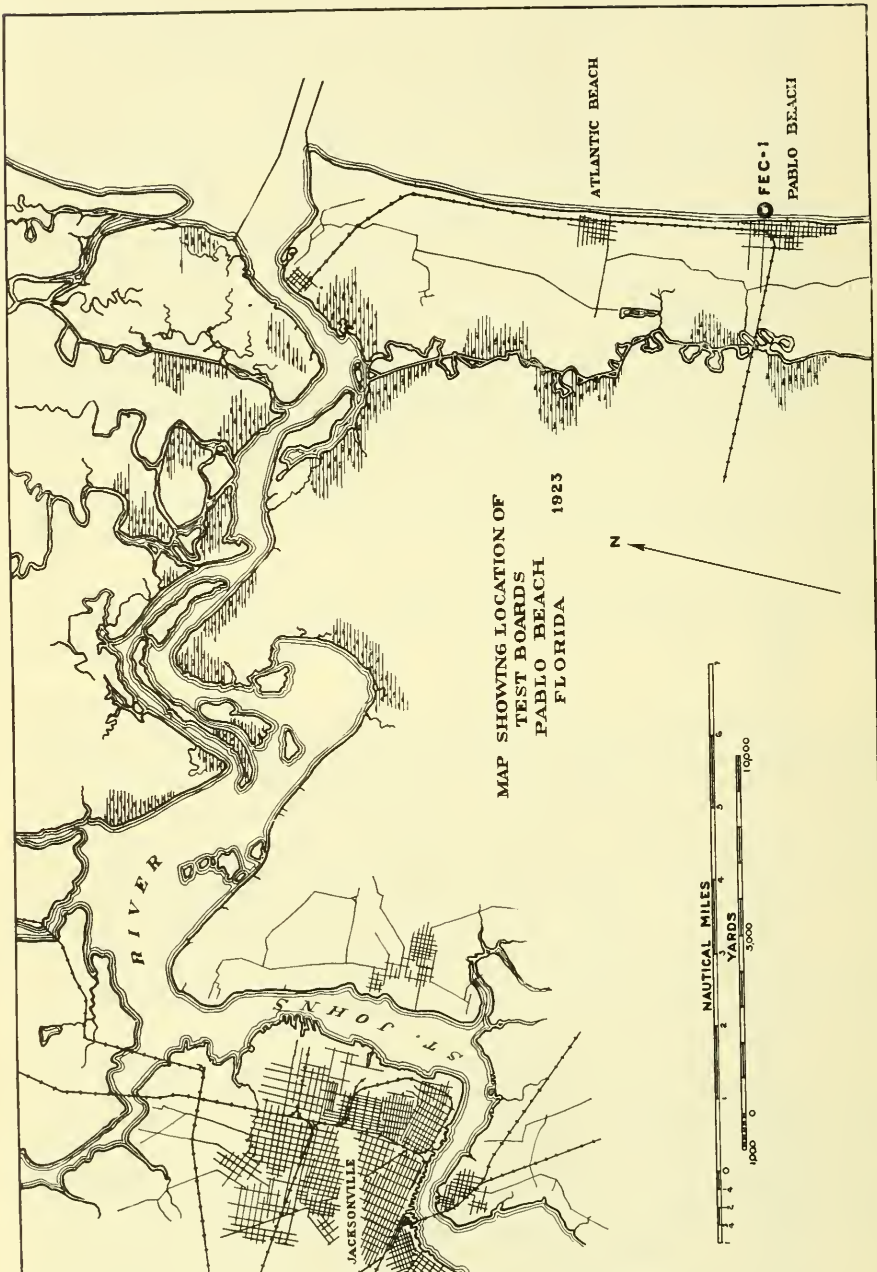

MAP SHOWING LOCATION OF
TEST BOARDS
PABLO BEACH
FLORIDA
1923
ATLANTIC BEACH
FEC-1
PABLO BEACH
N
ST. JOHNS
RIVER
JACKSONVILLE
NAUTICAL MILES
YARDS
5,000
10,000

FIG. 102

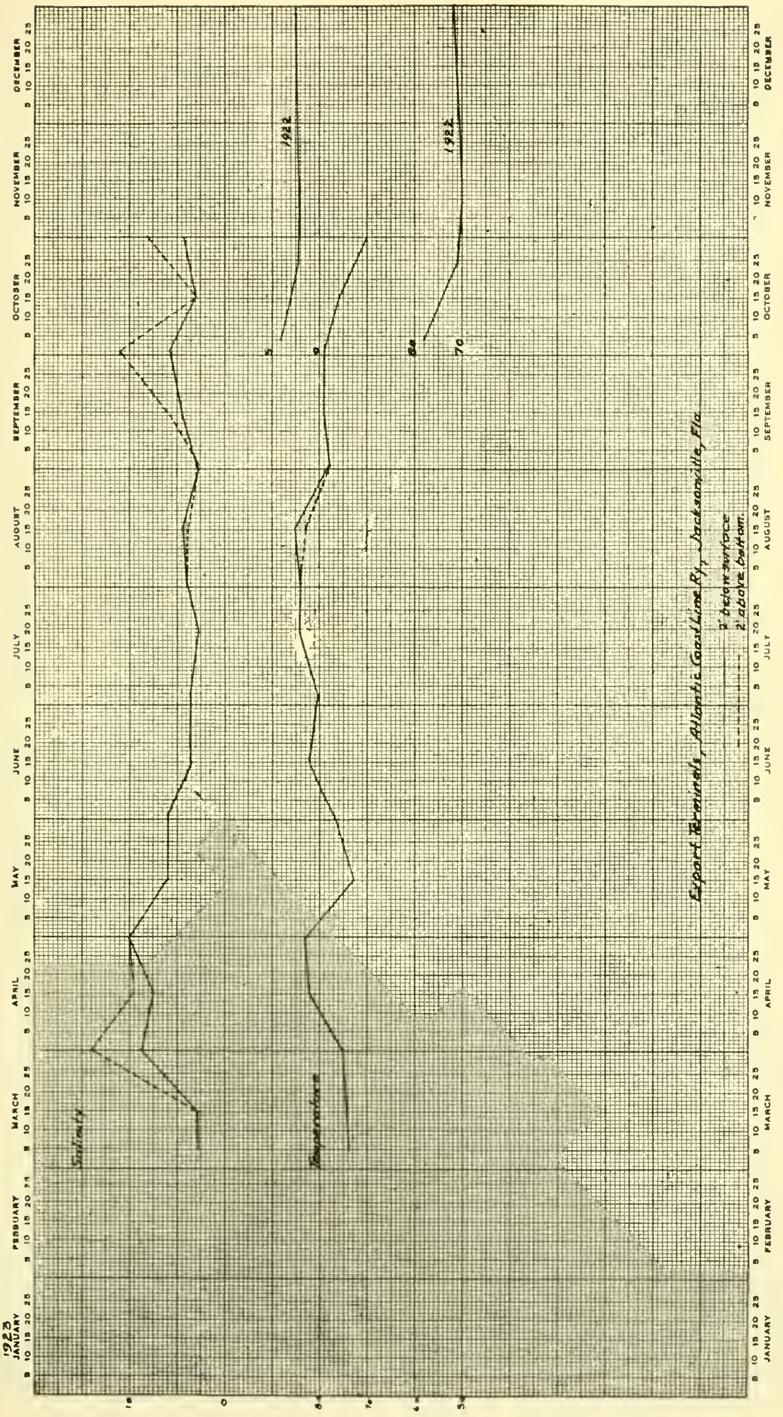


FIG. 103—SALINITY AND TEMPERATURE OBSERVATIONS, ATLANTIC COAST LINE RY. CO.'S EXPORT TERMINALS, JACKSONVILLE, FLA.

brands were used. The present condition of the jetty is practically the same throughout its entire length, so that it may be assumed that the various types of cement used gave practically the same quality of concrete. The sand used was of very poor quality, being round and extremely fine. All concrete was mixed by hand, the material for each batch being turned by shovels three times when dry and four times after the addition of water. It was cast in place in watertight forms, being carried to the desired location in wheelbarrows, and thoroughly tamped in place. The Portland concrete weighed 143.2 pounds per cubic foot when newly made, and 137 pounds when one month old. The Rosendale concrete weighed 133.3 and 131 pounds at like ages. At the present time all the concrete work on this groin is in very good condition, having in general suffered very little deterioration. Several blocks lying between low and high water show considerable corrosion on the upper surface. All exterior surfaces are, however, extremely hard and can be broken only with great difficulty. The sides of the blocks have been remarkably well preserved, and in many instances show very clearly the impression of the forms used in the construction. When small pieces of the blocks are chipped off, the interior or non-exposed surface may be readily disintegrated by the hands. This would appear to indicate that insufficient water to provide complete chemical action was used in the original construction, and that the outer surfaces, where a greater proportion of water appeared, were of a much more substantial construction."

"Groin No. 4, Anastasia Island, was constructed in 1890 and 1891. The concrete capping was composed of rectangular blocks 4 feet wide by 2.8 feet thick. Saylor's Brand of American Portland cement was used, the proportions finally adopted for the inner end of the capping being 1 part cement, 3 parts beach sand, and 5 parts coquina gravel. On the outer end of the groin the mixture was enriched to 1, 2, 4. The methods of construction were the same as described above for groin No. 1. This concrete has suffered considerable deterioration, particularly by flaking off in longitudinal cakes several feet in width and length, and about 6 to 7 inches in depth. The present appearance would indicate that the concrete had been placed in courses and that insufficient bond between successive layers had been secured. This condition probably resulted from the method of placing, which consisted of thoroughly tamping to a level surface after each deposit of several wheelbarrow loads of the mixture. This concrete can be readily broken up in large pieces, but the individual specimens thus secured show fairly good internal bond; and in fact cannot be disintegrated as rapidly as the concrete in groin No. 1."

"Two other groins were built on Anastasia Island in later years, but complete information as to methods and materials is not obtainable from the records. Their general condition is practically identical with that of groin No. 1."

Fort Marion—"Repairs to the Stairway arch, and in other parts of Fort Marion, were made in 1886 and 1887, all of the work being above high water level and not exposed to the direct action of sea water. Although records do not indicate the methods and materials used in this work, employes of this district recall that the same materials were used as for groin No. 1 described above; probably European Portland and Rosendale cements with fine bank sand and coquina gravel. All of this work is in excellent condition at the present time, showing but little deterioration."

Fort Taylor—"With reference to the concrete work in the sea wall at Fort Taylor constructed with the F. O. Norton Brand of Rosendale cement about 1856, the following is quoted from the report of Geo. E. Brown, Superintendent:

'A portion of this wall was demolished by the hurricane of 1910. The greater portion is still standing, however. Some erosion has occurred in the submerged portions of the wall, but the statement as to the apparent strength and durability of the face of the wall is still true. Concrete on top of the wall can readily be dug out with a knife; this is also true, however, of the soft limestone aggregate imbedded in the mortar; it is true also of concrete filling between the brick facings of the walls in old Fort Taylor proper, though the latter is slightly harder than that in the sea wall. Both

the concrete in the wall and fort are made up of the same proportion of cement and calcareous sand.

'The wall discussed is subjected to constant wave action, very heavy breakers in stormy weather. The depth of the wall varies from 8 feet to about 2 feet. The mixture was one part Rosendale cement, 7 parts broken limestone. In the breaking of this stone, sufficient pulverization of the material occurs to fill the voids of the aggregate. Displacement stone, varying in size, were also imbedded in the mixture; the largest of these displacement stones would weigh 8 to 10 pounds.' "

St. Johns River—"Some concrete blocks were used as capping for the north jetty at the entrance to the St. Johns River in 1888, and several blocks were placed at the inner end of the south jetty between 1888 and 1890. No record can be found giving the materials and methods of construction used. Inasmuch as the present appearance of these blocks is very similar to that of groin No. 1, Anastasia Island, which was constructed at the same time, it is very probable that the same materials were used. W. W. Fineren, Assistant Engineer, reports the present condition of these blocks as follows:

'These blocks are above low water and are not at all times submerged. There are no blocks on the jetties entirely submerged at all times. About 60 per cent of the blocks in question are submerged during the rising tide for about 20 per cent of the time, making them in water one-fifth of the time and in air four-fifths of the time; the other 40 per cent of the blocks are above high tide and are exposed to salt air only.

'Both the blocks partly submerged and the blocks entirely in air were examined carefully and no deterioration was observed. From the appearance of the blocks no chemical change has taken place and the blocks seem to be as good as when they were deposited over thirty years ago.' "

Conclusions

The best creosote impregnation does not seem to be efficient for more than 10 or 12 years, hardly a sufficient length of time to justify its use on important structures with permanent decks located in salt water.

Cast iron casings have good records, but piles used in cast iron casings should be protected against decay above high water.

The wrought iron structures of the Lighthouse Service are in good condition after nearly 70 years, which indicates that the use of this material is certainly worthy of consideration.

The concrete structures reported were built with cements not now on the market but generally their record is good.

The beginning of the period of borer inactivity at Fernandina is not clear but it appears to have ended in May; at Jupiter Inlet the close of the period of inactivity was at about the same time, while at Channel Five it appears from the record to have been slightly later.

The different species very evidently have different periods of inactivity but all of them appear to be inactive in the early spring.

KEY WEST, FLORIDA

Description of Harbor

Key West, (Fig. 104), lies northward of the Florida Reefs and is accessible to vessels of 26½ feet draft by several channels through the reefs and coral banks surrounding the harbor. The maximum tidal range recorded is 9.63 feet and the mean rise and fall of tide is 1.25 feet with an estimated current velocity on flood of 2½ knots and 3 to 3½ knots on ebb. Both the tidal range and currents are greatly affected by the wind. The prevailing winds are easterly except in the winter when they are northerly. During the West India hurricanes, which generally occur in September and October, wind velocities of 110 miles per hour have been recorded.

The channel at the Naval Station is 26 feet in depth and 800 feet wide. The depth at the wharves in the harbor varies from 10 to 26 feet.

The water temperatures in 1921 reached a minimum of 60° Fahr. in January and February and additional readings below 70° Fahr. were obtained in March, April, May, November and December. The average was 76.1° Fahr. and the maximum 88° Fahr. in June and August. Temperature and salinity from November 1, 1922, to September 1, 1923, are shown on Fig. 105.

Marine Borers

Past History—Shipworms are very active and were thought to attack with uniform intensity throughout the year. Both the Navy and Lighthouse Service report that the greatest damage is caused by *Limnoria* which will destroy an unprotected pile in from one to two years. They have also attacked creosoted timber.

Committee Investigations—Standard test boards were placed as shown below:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
South end of F. E. C. Bridge	FEC-7	Florida East Coast Railway	July 1, 1922	9.5	6.0
Quay Wall	*YD-701	Navy	Sept. 1, 1922	10.0	0.5
Quay Wall	YD-701A	Navy	Sept. 1, 1922	0.0	10.5

*Board suspended in a horizontal position.

The results of the inspections were as follows:

FEC-1—*Teredo* first appeared in block 2, removed August 1, increased in number reaching 100 in block 7, removed October 15, then decreased to from 7 to 12 in blocks 8, 9, 10 and finally increased again to from 50 to 100 specimens in the remaining blocks 11 to 16 inclusive. These proved to be of two new species, *Teredo clappi* and *Teredo sp. D.* About 90 per cent of the total number were *Teredo clappi.* A careful examination was made of the board together with the remaining original (Nos. 17-24) and replacement blocks (Nos. 1A-16A) which was removed from the water March 6, 1923. The results of this examination indicate that the shipworm attack began to be less severe on September 15 and gradually decreased until December 15 when it entirely ceased. It is very interesting to note the rapid decrease in *Teredo clappi* and increase in *Teredo sp. D. Limnoria lignorum,* the only organism other than shipworms in these blocks, also showed less activity from September 15 on, but persisted until February 15, 1923, 5 specimens appearing on this block. On the date of the removal of the old, a new board of 1923 model was substituted. The first appearance of shipworms on the new blocks occurred on the second series, removed May 1. The center block of this series which had been in the water one month contained about 50 shipworm embryos, all belonging to *Teredo sp. D. Teredo clappi* appeared one month later. The last blocks, which were removed October 8, showed the tubes of the shipworm protruding through the wood, a condition due to the severe action of *Limnoria.* Bryozoa was the only associated organism and was found on a few blocks only.

YD-701 and 701-A—These boards were located very near to FEC-7 and the results of the test were similar to and confirmatory of those found at that point. Three other species of *Teredo* were found in small numbers, viz.: *Teredo bipartita, Teredo thompsoni* and *Teredo* (*Psiloteredo*) *sp. Q*, the last named being new.

It will be seen from the foregoing that a period of immunity from shipworm attack existed for about four months, from December 15 to April 15, and that although *Limnoria* action was considerably diminished during the same period, it did not altogether cease.

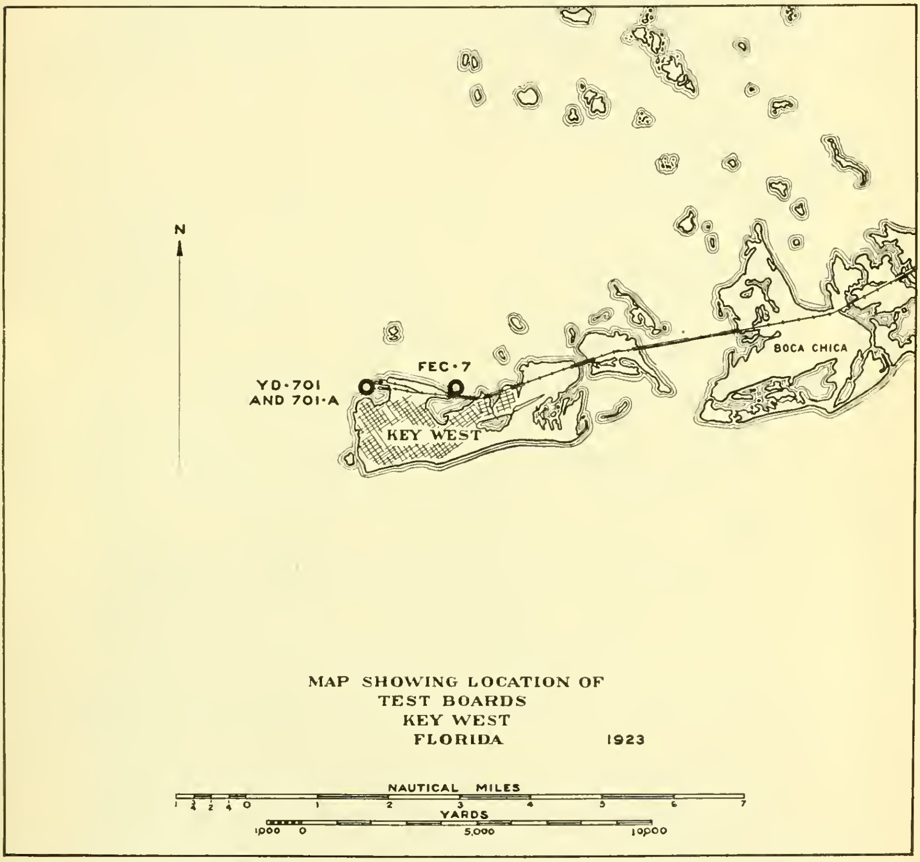


FIG. 104

Methods of Protection

Creosote Impregnation—The U. S. Government Departments have all used creosoted piles with a treatment ranging from 12 to 24 pounds per cubic foot. Yellow pine sheet piles containing 16 to 20 pounds in Naval structures are reported to show the first damage in from 7 to 8 years and to be destroyed in about 12 years. Some small piers were built in 1920-22 with piles containing only 12 pounds of creosote but although surface in-

spection has not yet shown any damage this treatment is considered too light by the Bureau of Yards and Docks.

The Corps of Engineers, U. S.A., consider that the average life of piles, containing 22 pounds of creosote per cubic foot, is about 12 years and the Lighthouse Service since 1920 have been specifying 22 pounds of grade B creosote.

Armor—Terra cotta pipe armor filled with sand has been used with poor results on account of breakage, but cast iron pipe is reported to be efficient by the Lighthouse Service when it is set deep enough in the bottom so that the unprotected pile will not be exposed by scour. Some trouble was experienced on account of the decay of the piles above water level.

Concrete armor has been tried with varying success by the three bureaus, but the Lighthouse Service reports that the life of the structure was shortened by dry rot as in the case of cast iron pipe.

Substitutes for Timber

Wrought Iron and Steel—Pier A of the Navy Department was built in 1879 on hollow wrought iron piles with a shell thickness of ¾ inch. It was removed in 1911 to meet the requirement of heavier loading and the piles were found to be unaltered below the mudline, in good condition up to mean low water, and badly pitted, though not destroyed, above mean low water. Solid 6-inch steel piles driven in 1898-1900 are also reported by the Bureau of Yards and Docks to be in good condition.

Concrete—Concrete structures are reported as follows:

Object	Mixture	Cement Brand	Aggregate	Imbedment of Steel	Consistency	Condition 1922
Navy Dept. Quay Wall 1911-12						
1. Piles	1:2:3	Lehigh	1½″ gravel and silica sand from L. I.	1½″-2½″	Flow, but not run	Generally poor
2. Beams	1:2:3	Lehigh	1½″ gravel and silica sand from L. I.	¼″-1½″	Generally wet	Generally poor
3. Slab	1 2.4	Lehigh	1½″ gravel and silica sand from L. I.	½″-1	Generally wet	Generally poor
Pier "A"—1912						
4. Precast Cylinders	1:1½:3	Atlas	Silica sand and ¾″ gravel	1½″	Flow, but not run	Generally fair.
5. Beams and Slabs	1:2½:5	Atlas	1½″ gravel	1½″	Flow, but not run	Generally fair.
Pier "B"—1912						
6. *Deck	1:2:4	Vulcanite	¾″ gravel and silica sand	1½″	Flow, but not run	Good.
7. Coal Shed "A" Extension	....	....	....	....	Flow, but not run	Good.
8. Under water	1:1½:3	Atlas	Silica sand and 1½″ gravel	1½″	....	....
All others	1:2½:5	Atlas	....	1½″	....	....
9. Coal Shed "B" †Sheet Piles	1½:3	Vulcanite	Gravel and sand	1½″	Flow, but not run	Good.
Lighthouse Service						
10. Reinforced Concrete Piles—1915	....	....	....	** 2% of section	....	Cracks from 4′ below M. L.W. to 2′ above H.W.

*This deck is made of arches sprung between "I" beams, 2′4″ on center and is not a typical reinforced job.
†The tops of these piles are below water.
**Ratio of reinforcement section to total section.

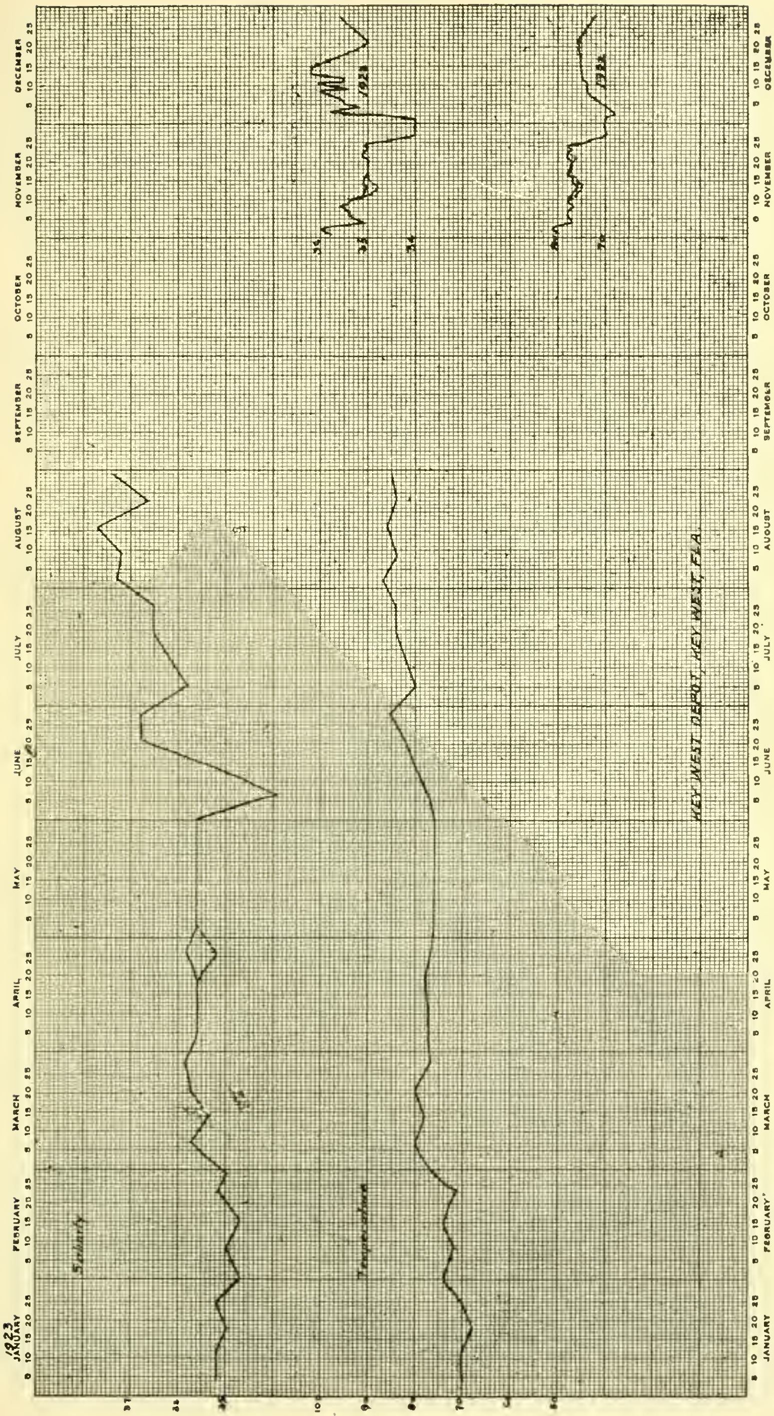


FIG. 105.—SALINITY AND TEMPERATURE OBSERVATIONS, LIGHTHOUSE DEPOT WHARF, KEY WEST, FLA.

All of these structures are said to have been built with great care and in conformity with the best practice at the time of their construction. The piles were kept moist 20 days and were seasoned 60 days before driving. Almost every pile is cracked above low water over each reinforcing rod. In 1914, 40 piles were cast, using a broken brick aggregate and 14 of them were driven. With the exception of one, which was defective, all were reported in good condition. They have never been decked and consequently are well ventilated, but it is not improbable that the replacement of a part of the inert aggregate by silica in its active form from the broken brick, may have something to do with their condition.

Tests

One pile sheathed with copper .021 inch thick and one with monel metal .021 inch thick were driven May 23, 1923, at the edge of the Key West Depot Wharf of the Lighthouse Service just inside the fender line. The sheathing materials were furnished by the manufacturers and the test is in charge of the Superintendent of Lighthouses of the District.

Conclusions

No unprotected timber structures which are required to stand in this harbor over one year should be constructed.

A period of immunity from the attack of molluscan borers of from three to four months between December and April may be expected, but no such period will be free from *Limnoria* attack.

Thoroughy creosoted piles may be expected to have an average life not exceeding 12 years.

The record of wrought and cast iron is good and long life may be expected from properly designed and built structures.

Most of the concrete structures show deterioration, but their present age is not sufficient to permit their useful life to be predicted.

GULF OF MEXICO—MISSISSIPPI RIVER TO KEY WEST*

General Description

The coast line of this region is generally low and sandy. From Key West to Apalachee Bay the bottom is largely of coral formation. From Mississippi Sound west the bottom is sand and silt with several shoals lying well off shore, which change to some extent with severe storms.

Tampa Bay (Fig. 111) is the approach to Hillsboro and Old Tampa Bays. It is about 20 miles long and 6 to 7 miles wide. For a distance of 15 miles above the entrance it has a least depth of 22 feet along its axis, between broad shoals that extend from the shores on both sides. A dredged channel 200 feet wide and 25 feet deep leads to Port Tampa.

Hillsboro Bay, the northeastern arm of Tampa Bay, at the head of which is situated the city of Tampa, is 8 miles long and 4 miles wide, and has a dredged channel 200 feet wide and 24 feet deep leading through it from the deeper water of Tampa Bay to a turning basin at the mouth of the Hillsboro River. The Hillsboro River, which flows through the middle of the City of Tampa, has a dredged channel 200 feet wide and 12 feet deep from the turning basin to the first drawbridge.

Old Tampa Bay, the northwestern arm of Tampa Bay, is about 12 miles long and 6 miles wide, the narrowest part being at its junction with Tampa

*Mobile and Key West Harbors not included.

Bay, where the width is only 2½ miles. It is generally shallow with depths of 5 to 15 feet, except at its southern end, where a deep channel runs along the eastern side about ¾ mile off shore. On this stretch of the eastern shore is located Port Tampa, where there are depths of 18 to 24 feet alongside the docks.

St. Petersburg is situated on the west shore of Tampa Bay. At the Municipal Pier, where the test board is located, there is a depth of 17 feet.

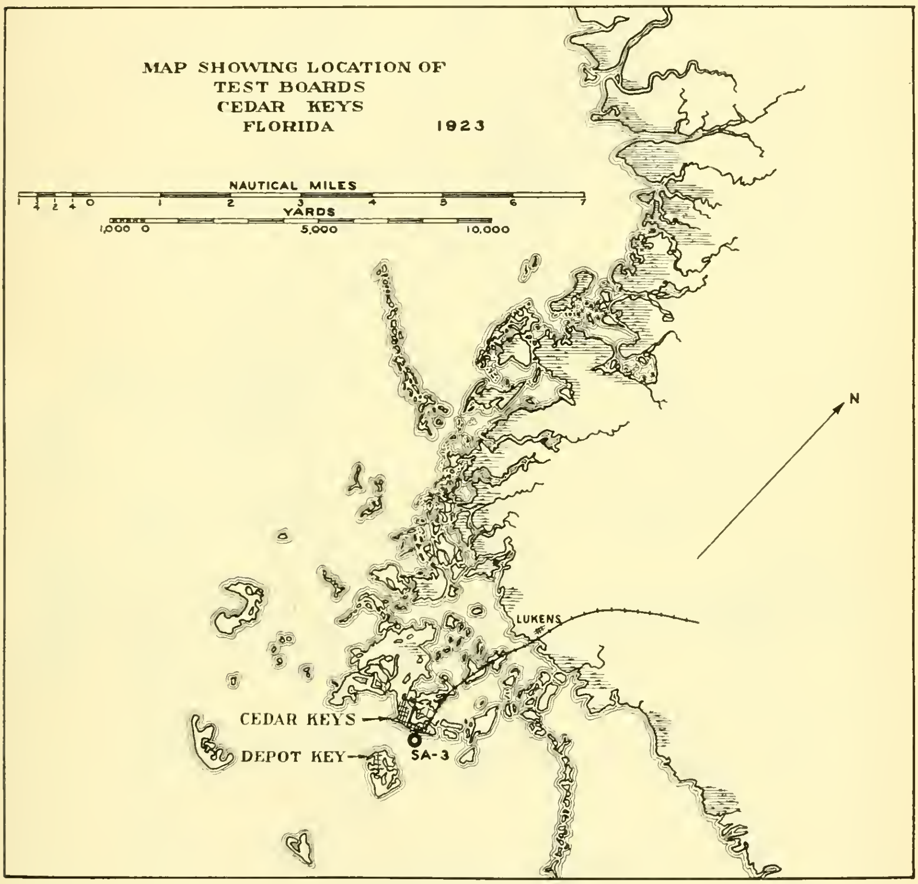


FIG. 106

Fort Dade is located on Egmont Key at the entrance to Tampa Bay.

The mean rise and fall of tides is 1.4 feet at Egmont Key, and 2.2 feet in Hillsboro and Old Tampa Bays.

The town of Cedar Keys (Fig. 106) is located on Way Key, about midway between Tampa Bay and Cape San Blas. It is the terminus of a branch of the Seaboard Air Line. The mean rise and fall of the tides at this point is 3 feet, and there is a depth of 10 feet at the wharf.

St. Andrews Bay (Fig. 107) is a narrow, irregularly shaped landlocked

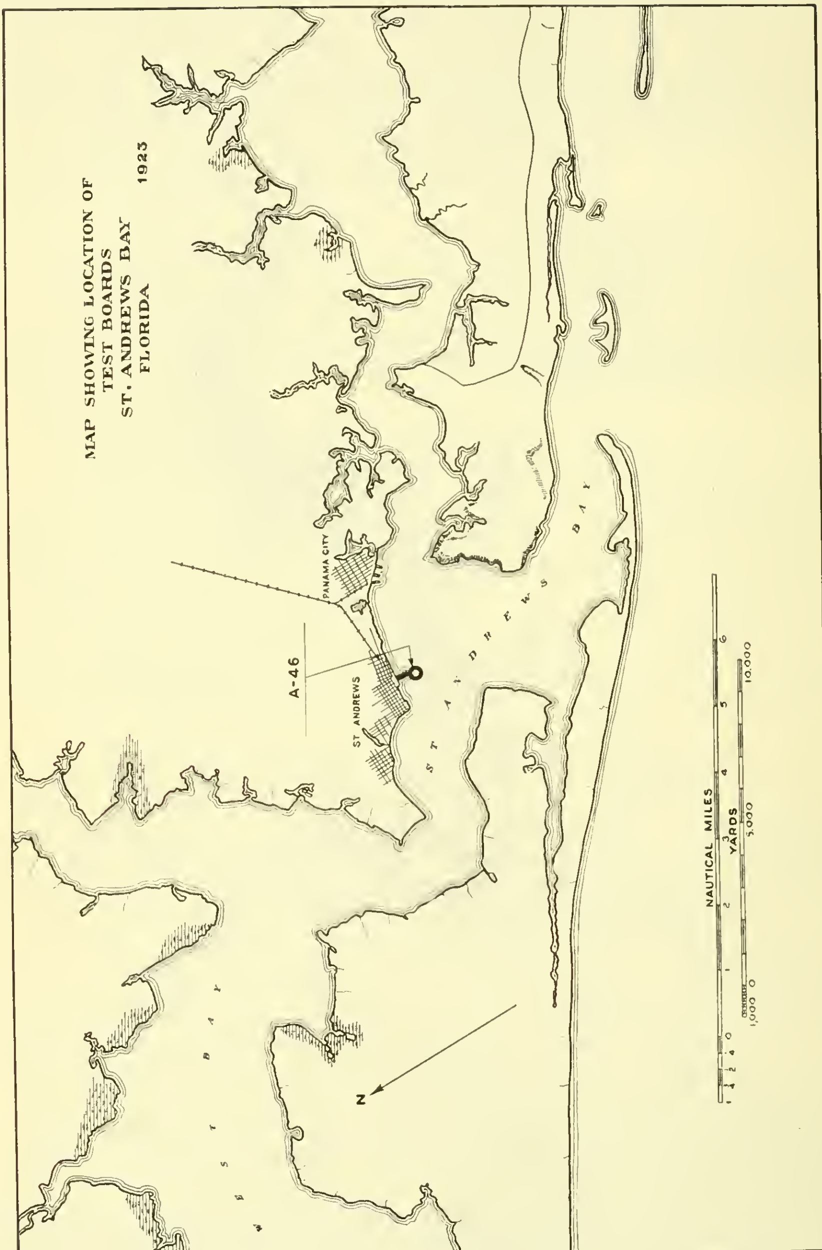

MAP SHOWING LOCATION OF
TEST BOARDS
ST. ANDREWS BAY
FLORIDA
1923
A-46
PANAMA CITY
ST ANDREWS
S T A N D R E W S B A Y
W E S T B A Y
N
NAUTICAL MILES
YARDS

Fig. 107

harbor of moderate depth lying 27 miles northwestward of Cape San Blas. The mean rise and fall of the tides is 1.4 feet.

Pensacola Bay (Fig. 108), one of the important harbors of the Gulf Coast, is about 12½ miles long and 2½ miles wide. Two test boards are located in this bay, one at Fort Pickens on Santa Rosa Island, at the entrance to the Bay, the other at the Naval Air Station Wharf at Warring-

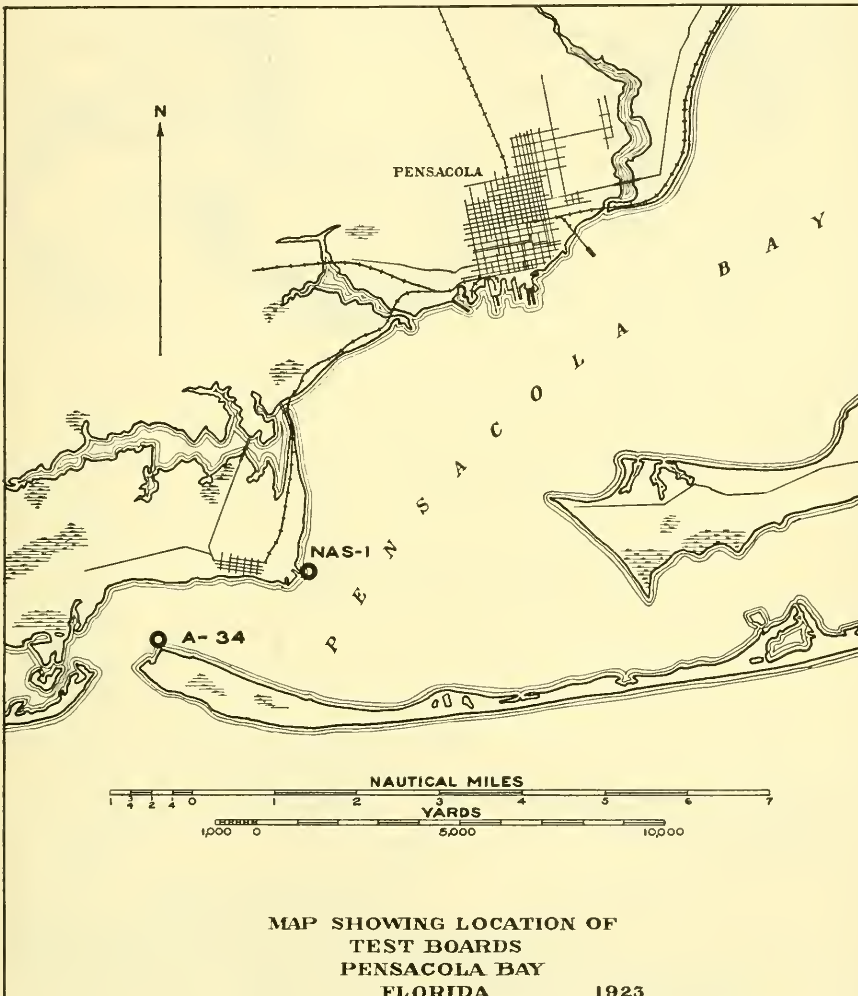


Fig. 108

ton, a small town on the north shore about 2½ miles above the entrance. The mean rise and fall of tides is 1.4 feet.

Mississippi Sound extends 70 miles west of Mobile Bay between a chain of long, narrow, low sand islands and the main land, to Lake Borgne, which in turn is connected with Lake Pontchartrain (Fig. 112) by The Rigolets, a deep passage 7½ miles long and ¼ mile wide.

A dredged channel 17 feet deep leads from Horn Island Pass to Pascagoula (Fig. 109) and thence up the Pascagoula River for a distance of about 9 miles. The tidal range at Range Beacon FR—A is 3.75 feet and at U. S. Boat Yard 3.9 feet.

A dredged channel 200 feet wide and 17½ feet deep leads from Ship Island Harbor to Gulfport (Fig. 110). The tidal range at Ship Island

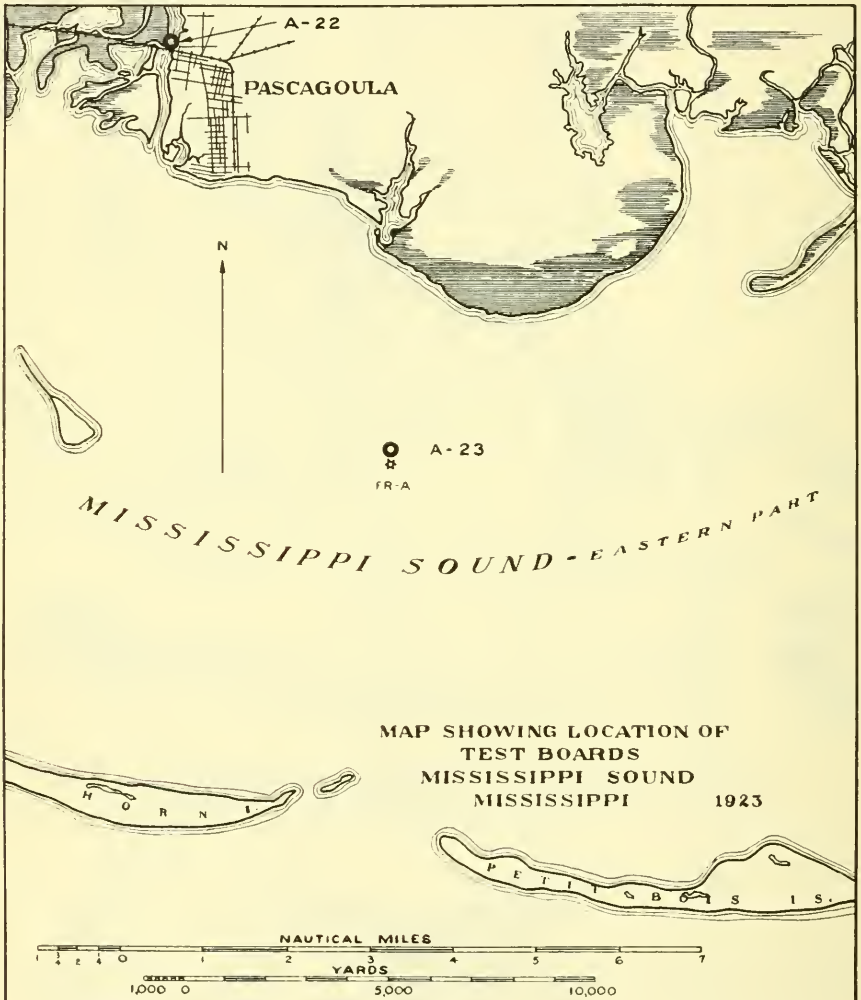


Fig. 109

Lighthouse is 3.5 feet; at Range Beacon FR—4, 3.5 feet, and at the Gulf & Ship Island Railroad pier, 2.0 feet.

One test board was placed in the Gulf of Mexico in rear of the lighthouse at the mouth of South Pass (Fig. 113); two test boards were placed in the Mississippi River, one at Quarantine and one at Fort Jackson. The

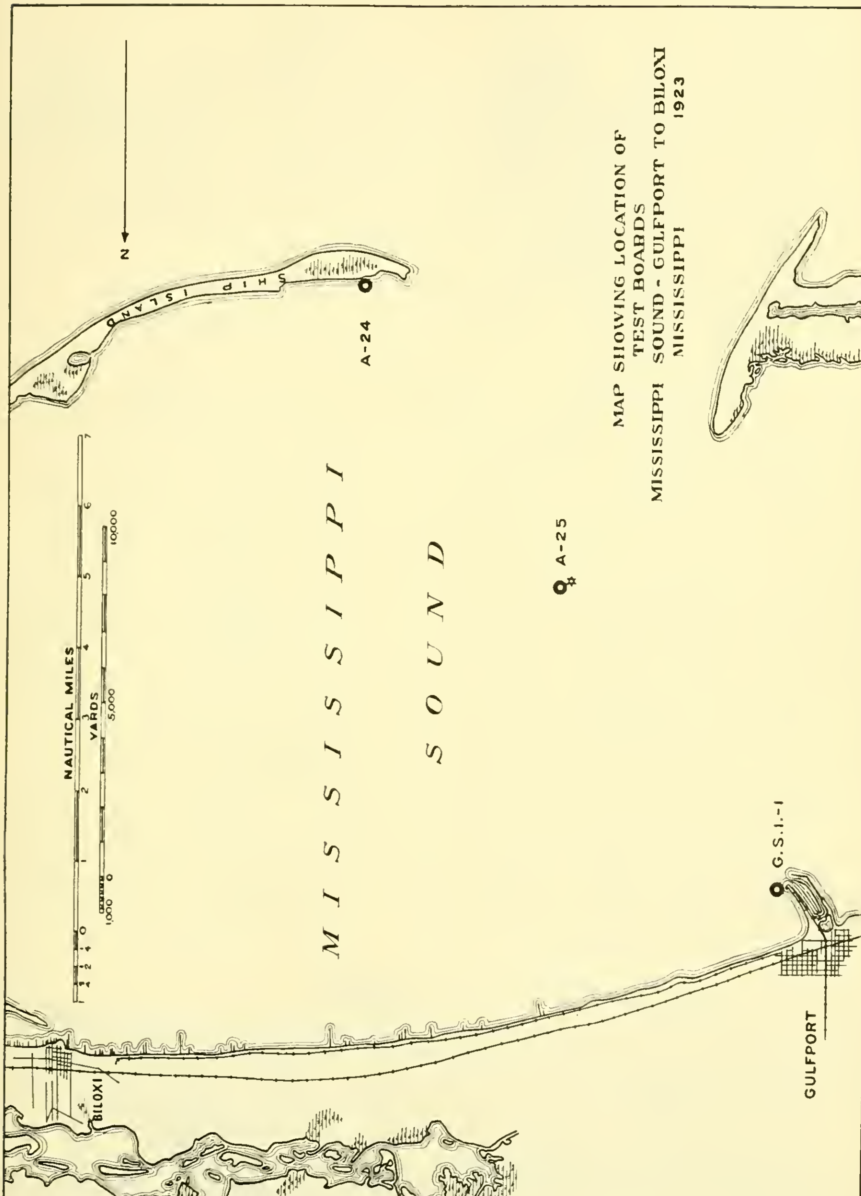

MAP SHOWING LOCATION OF
TEST BOARDS
MISSISSIPPI SOUND - GULFPORT TO BILOXI
MISSISSIPPI
1923
N
SHIP ISLAND
A-24
A-25
G.S.I.-1
MISSISSIPPI
SOUND
NAUTICAL MILES
YARDS
GULFPORT
BILOXI

FIG. 110

board in rear of the lighthouse is in a location where the water varies from full salt to brackish, whereas the other two boards are so located that the water is entirely fresh, except for short periods of time during the extreme low water period of the river.

Marine Borers

Past History—Marine borers have always been troublesome in this territory, except in the Mississippi River above Port Eads, where the water is practically fresh for the greater part of the year. Untreated timber appears to have had a life of from one to two years in the coastal region between the mouth of the Mississippi River and St. Andrews Bay. In Tampa Bay four years is the maximum service period, but the average is little more than one year.

Committee Investigations—Test boards were installed as follows:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Hillsboro Bay—S. A. L. Phosphate Wharf, Seddon Island	SA-2	Seaboard Air Line	Oct. 15, 1922	14.0	7.0
Hillsboro Bay—Seddon Island	A-10	Army	Sept. 1, 1922	6.0	8.0
Port Tampa Slip—Old Tampa Bay	A-12	Army	Sept. 1, 1922	7.0	8.0
St. Petersburg	A-11	Army	Sept. 1, 1922	4.0	7.5
Fort Dade	A-26	Army	Sept. 1, 1922	0.5	7.7
Cedar Keys	SA-3	Seaboard Air Line	Oct. 15, 1922	1.5	6.0
St. Andrews Bay — Fishhouse Wharf	A-46	Army	Feb. 1, 1923	......	......
Pensacola Bay—Naval Air Station Wharf	NAS-1	Navy	Nov. 16, 1922	......	......
Pensacola Bay—Fort Pickens	A-34	Army	Nov. 1, 1922	1.0	6.5
Pascagoula Harbor—Range Beacon FR-A	A-23	Army	Oct. 12, 1922	1.1	15.8
Pascagoula Harbor—U. S. Boat Yard	A-22	Army	Oct. 11, 1922	0.8	10.0
Gulfport Harbor—Ship Island Lighthouse	A-24	Army	Oct. 15, 1922	*1.0	......
Gulfport Harbor—Range Beacon FR-4	A-25	Army	Oct. 15, 1922	1.0	16.6
Gulfport Harbor—G. S. I. South Wharf	GSI-1	Gulf & Ship Island Ry.	Sept. 22, 1922	1.0	7.5
Lake Pontchartrain — So. Ry. Bridge at South Point	S-8	Southern Ry	Oct. 1, 1922	1.8	8.0
Manchac Pass—I. C. Railroad Bridge	IC-1	Illinois Central R. R.	Oct. 15, 1922	6.0	9.0
Gulf of Mexico—Port Eads	A-36	Army	Oct. 15, 1922	0.5	6.0
Mississippi River—Quarantine	A-45	Army	Dec. 15, 1922	0.5	13.5
Mississippi River—Fort Jackson	A-44	Army	Dec. 15, 1922	0.5	14.0

*Board suspended in a horizontal position.

Results of inspection of blocks are as follows:

SA-2—The first four blocks were covered with small barnacles. Specimens of *Bankia gouldi* first appeared in block 5, removed January 15, 1923, together with barnacles and a few specimens of *Mytilus*. Block 13 removed May 1 was completely destroyed by *Bankia gouldi* with tubes up to 12 inches in length. Some examples of *Bankia sp. I* were found. The old board was replaced by the revised type, August 1, 1923, and no shipworms appeared during the next two months. Associated organisms were *Balanus* and *Mytilus*.

A-10—The first specimens of *Bankia gouldi* appeared in block 4, removed November 4, 1922. First *Bankia sp. I* appeared in block 6, removed December 2. *Teredo bartschi* appeared in subsequent blocks. The old board

FIG. 111

MAP SHOWING LOCATION OF
TEST BOARDS
TAMPA BAY
FLORIDA 1923

MAP SHOWING LOCATION OF TEST BOARDS LAKES MAUREPAS AND PONTCHARTRAIN LOUISIANA 1923

was replaced March 3, 1923, by a new board of the 1923 model. Center block 2, submerged for one month, removed May 4, contained numerous specimens of *Bankia,* and center block 3, immersed for one month, removed June 4, showed practically complete destruction by these two species of *Bankia,* which on August 8 had reached a length of 7 to 8 inches. Associated organisms were *Balanus, Mytilus* and *Ostrea.*

A-12—Shipworms appeared on first block, removed September 20, 1922, associated with *Balanus* and encrusting Bryozoa. Destruction proceeded rapidly. A new board was substituted February 20, 1923. Shipworms identified were *Teredo bartschi, Bankia gouldi* and *Bankia sp. I. Limnoria* damage was considerable. *Teredo* was confined to upper and *Bankia* to

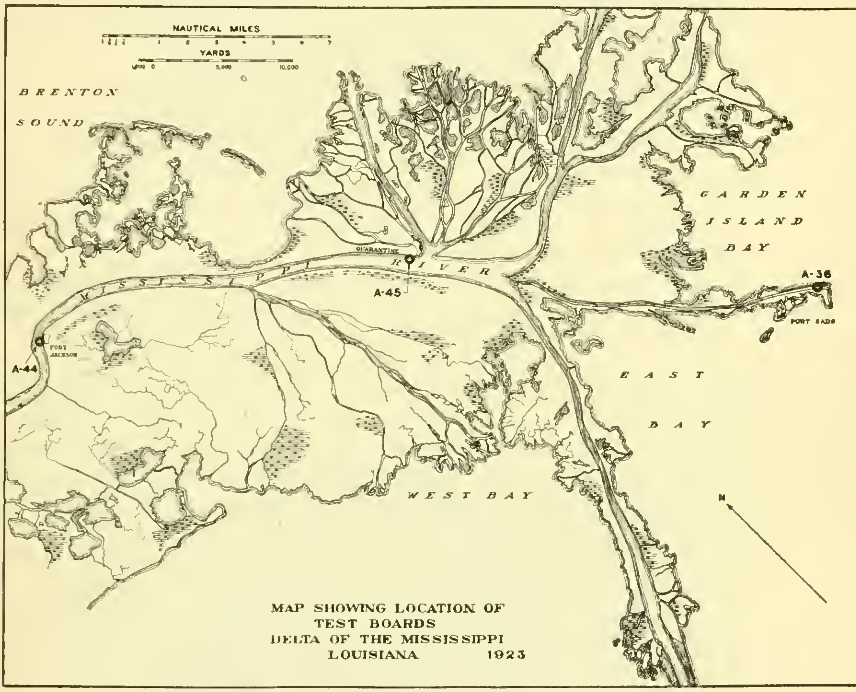


FIG. 113

lower blocks. The end of the season of activity was established as prior to December 1, 1922. The attack of *Teredo bartschi* commenced in April and the first specimens of *Bankia* were found in May; by July the specimens of *Teredo* had reached a length of 4 inches and those of *Bankia* 6 inches, while on September 5, *Bankia* had increased in length to 10 inches. Associated organisms were *Balanus,* Bryozoa and Algae. *Limnoria* attack was fairly heavy. A section of a pile from Sneads Island, Manatee River, showed complete destruction by *Bankia gouldi* and *Martesia striata* after one year's service (Fig. 114). Shipworms were not hitherto known to exist at this particular location.

A-11—Destruction was less rapid than at A-12. In addition to organisms found at A-12, there were present *Teredo navalis* and a few specimens of

Martesia. *Limnoria* damage was the same as at A-12. The end of the season of activity was prior to December 15, 1922, but specimens of *Bankia* 12 inches long were found in the block removed February 1, 1923. The first shipworms appeared on new board installed March 2, 1923, between May 3 and June 8, though it is probable that the attack commenced in April. The *Limnoria* attack was so heavy that many of the shipworms were killed. Associated organisms were *Balanus,* Bryozoa, Anomia and Algae.

A-26—Destruction by *Bankia gouldi, Teredo navalis* and *Teredo bartschi* was rapid. Some specimens of *Teredo* (*Psiloteredo*) *sp. Q* were found. Great damage was done by *Martesia* and *Limnoria.* The end of the season of activity was between December 1 and 15. The first shipworms appeared on the new board, installed March 3, 1923, between July 5 and August 2, and the attack appeared to be much lighter in the summer of 1923 than in the autumn of 1922. Associated organisms were *Balanus,* Bryozoa, Mytilus and Algae.

SA-3—*Teredo bartschi* was the only species of shipworm found, and the attack was of medium intensity. The 1922 season of activity ended between November 1 and 15. The 1923 season began prior to May 22. *Limnoria* damage was considerable, and a few specimens of *Martesia* were found. Associated organisms were *Balanus,* Bryozoa (both *Lepralia* and *Bugula*), Ostrea, Anomia and Algae.

A-46—Damage by *Limnoria* severe. One specimen of *Bankia gouldi* was found in block 5, removed May 1, 1923. The board was abandoned after removal of block 6. Associated organisms were *Balanus,* Bryozoa.

NAS-1—The first specimen of *Bankia gouldi* appeared in block 7, removed March 1, 1923. Destruction proceeded rapidly. A few specimens of *Teredo* (*Psiloteredo*) *sp. Q* and *Bankia sp. I* were also found. *Limnoria* action was severe. Associated organisms were *Balanus* and Bryozoa. A section of a pile treated with 20 pounds creosote and driven in 1902 was completely destroyed by species of *Bankia,* principally *Bankia gouldi,* assisted by *Martesia* and *Limnoria lignorum.*

A-34—Destruction by *Bankia gouldi* was rapid. The beginning of the 1923 season of activity was about April 1. Other shipworms found were *Bankia sp. C* and *Teredo* (*Psiloteredo*) *sp. Q*. *Limnoria* action was of medium intensity. Associated organisms were *Balanus,* Bryozoa, Anomia.

A-23—*Bankia gouldi* appeared on block 1, removed November 1, 1922, and 10 to 20 specimens were found in each of the succeeding blocks, including block 11. Block 7, removed February 1, contained a specimen of *Bankia gouldi* 7 inches long and block 9, one month later, one 10 inches long. Block 12, removed April 16, was completely filled with *Bankia gouldi.* Later blocks were filled with *Bankia* and a few specimens of *Martesia.* Associated organisms were *Balanus,* encrusting Bryozoa and Algae.

A-22—*Bankia gouldi* was found in block 5, removed January 1, 1923. One to two specimens were found in succeeding blocks up to No. 12, which contained about 100. One specimen of *Teredo bartschi* also appeared. Associated organisms were *Balanus* and Bryozoa.

A-24—In blocks 2 to 13, 2 to 10 small specimens of *Bankia gouldi* and *Bankia sp. C* were found. Block 14, removed May 16, 1923, contained about 50 specimens and by the end of June the blocks were completely filled with *Bankia gouldi,* and a few specimens of *Bankia sp. C*. *Limnoria* was present

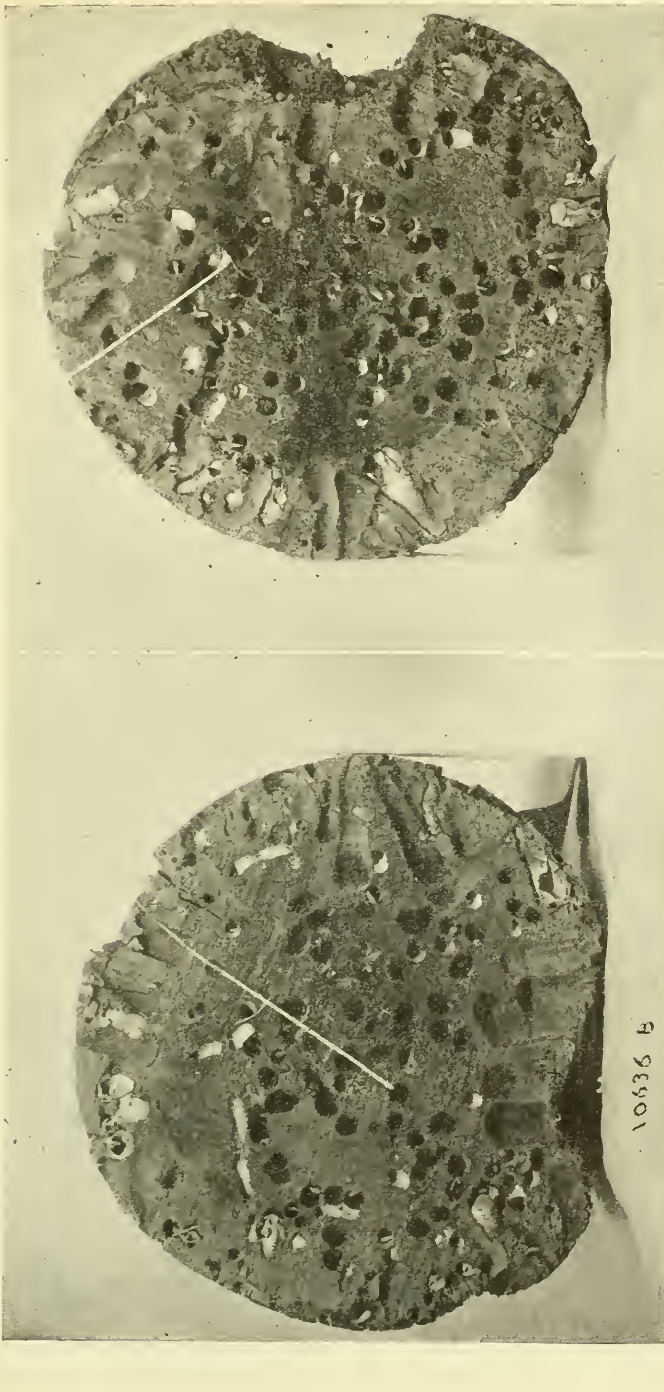


FIG. 114—SECTION OF UNPROTECTED PINE PILE WITH ONE YEAR'S SERVICE AT THE MOUTH OF THE MANATEE RIVER, TAMPA BAY. ATTACKED BY *Bankia* AND *Martesia*.

in considerable numbers. Associated organisms were *Balanus,* Bryozoa, Ostrea and Algae.

A-25—*Bankia gouldi.*—One to 20 specimens were found in Blocks 3, removed December 1, 1922, to 21, removed September 2, 1923, some of them nearly 12 inches long. Associated organisms were *Balanus,* Bryozoa and Algae.

GSI-1—Block 1, removed October 1, 1922, contained 10 specimens of *Bankia gouldi.* Block 2 and succeeding blocks were completely filled with this species, accompanied by a few specimens of *Teredo bartschi.* A new board was substituted April 10, 1923, and the first appearance of *Bankia gouldi* was on center block 2, between May 10 and June 10; center block 3, removed July 10, contained 100 small specimens, and total destruction occurred in three to four months. The growth was about 1½ inches the first month. Associated organisms were *Balanus,* Bryozoa and Ostrea.

S-8—A few specimens of *Balanus improvisino* Darwin, encrusting Byrozoa and Algae were found, and while *Sphaeroma* had attacked piles in the trestle, none appeared on the blocks.

IC-1—A few *Sphaeroma* borings were found, also some specimens of *Balanus* and Algae.

A-36—*Bankia gouldi, Teredo bartschi* and a species of *Sphaeroma* were found, and the destruction was rapid. The season of activity ended between December 1 and 15, 1922, and the first appearance of *Bankia gouldi* in 1923 was between May 23 and June 19; by July 17 specimens had reached a length of over 6 inches. Associated organisms were *Balanus,* Bryozoa (*Lepralia*) and Algae.

A-45—No life of any kind.

A-44—No life of any kind.

Salinity and temperature observations were carried on by the army at Fort Pickens, Port Eads and Gulfport, and by the Southern Railway at Lake Pontchartrain. These are shown on Figs. 115-119 inclusive.

The Seaboard Air Line Engineering Department has under observation at Tampa, Seddon Island, a nail-studded test piece 4 inches by 4 inches by 5 feet. The nails used are ordinary roofing nails having ⅜-inch heads. They were spaced ½ inch apart and in rows ¾ inch center to center. The test piece was placed in the water June 10, 1923.

Methods of Protection

Creosote Impregnation—This method of protection has been in general use in this territory from its earliest development. By this means the life of timber is extended to from 8 to 15 years when the process is carefully performed and the material well selected. Unless treated to refusal. however, timber will have a much shorter life. Piles treated with 20 pounds per cubic foot and driven at the Navy Yard at Pensacola were found to be completely destroyed in 1922. Piles in various other wharves at Pensacola showed a service life of from 5 to 11 years, the treatment ranging from 20 to 24 pounds. At the L. & N. wharves a life of 20 years was obtained from piles averaging 22 pounds absorption. Experiments with creosote fractions were carried on by the Forest Products Laboratory, Department of Agriculture, at Pensacola and Gulfport, and will be found reported on page 142.

Pile Coatings—Experiments with Reed's Wood Preservative, Barol, Coppered Carbolineum and Kennon's Marine Preservative, applied to pontoons,

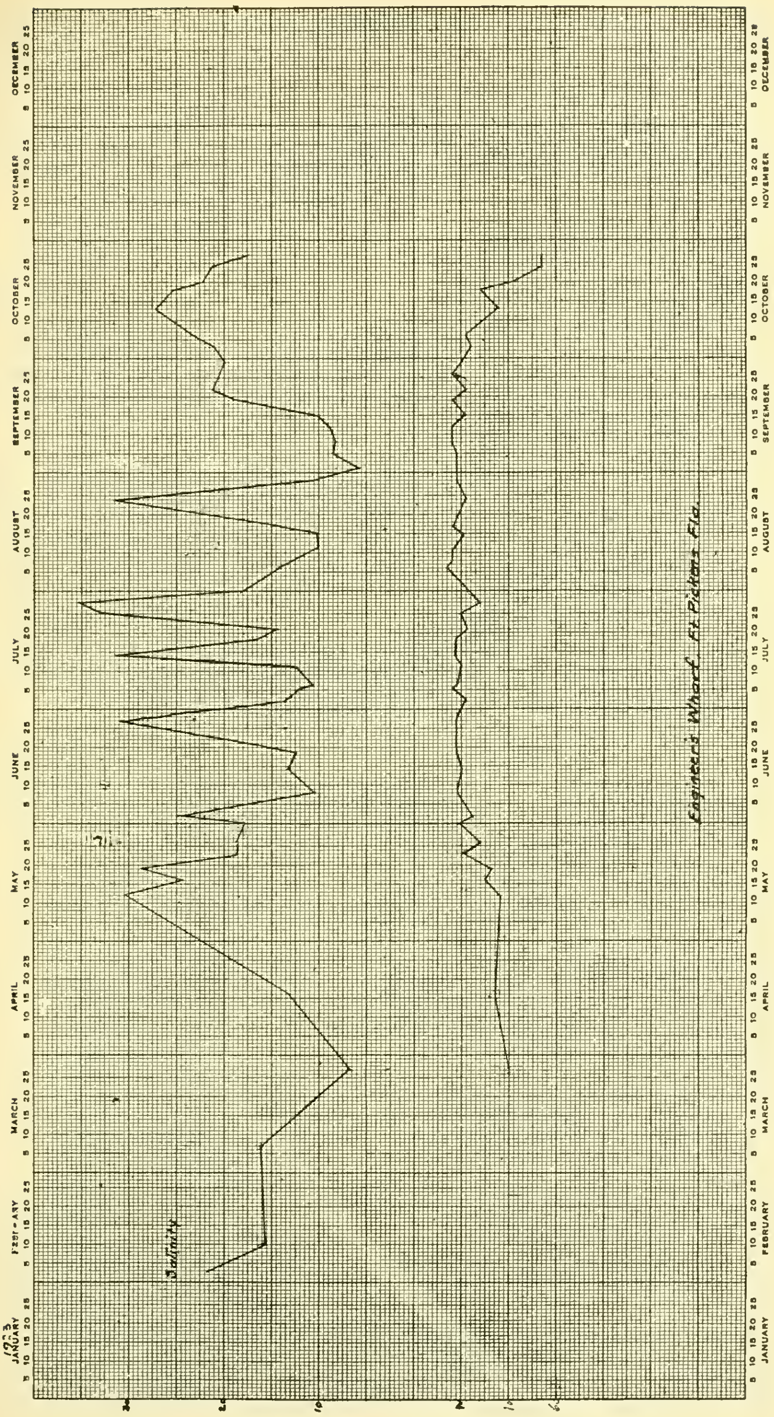


FIG. 115—SALINITY AND TEMPERATURE OBSERVATIONS, FORT PICKENS, FLA.

were made by the Army in Hillsboro Bay and at the mouth of Manatee River, in the summer months of 1915, and from March to December, 1917. The pontoons on which the paints were applied were stored in fresh water during the period September 1, 1915, to March 1, 1917. Of the three paints tested, the Barol appeared to have the most lasting qualities. None of them stopped the *Teredo* attack, but it was thought that results with the Reed's Wood Preservative were such that with successive coatings at 6 to 8 months intervals an economical protection would be secured.

Armors—Vitrified pipe, cast iron pipe and concrete jackets have all been used as protection in these waters. The breakage of vitrified pipe has been such that it is no longer employed, except in still water, where such breakage is improbable. The first cost of cast iron pipe protection and the fairly rapid decay of the unprotected piles above the armor, combine to make this method of questionable economy unless the timber receives preservative treatment. The engineer officers of the U. S. Army state that the protection secured from concrete jackets depends upon the character of the work and the location.

Yellow or Muntz metal has been used as sheathing for piles. The oldest structure so protected of record is a boat house at St. Marks, Fla., built about 1907. Repairs were necessary in 1913 and a recent inspection showed the metal to have become quite brittle and its further service doubtful. The piles of a boat house at Ship Island Lighthouse, built about 1912, were sheathed with yellow metal. Deterioration in 1922 was such that it was decided to incase them with vitrified pipe.

Many lighthouse structures in this district are built on piles protected with cast iron pipe. A partial list follows:

Name of Structure	Location	Date Built	Condition Reported in 1922
Punta Rassa Range Front Light, Fla.	San Carlos Bay, Fla.	1904	*
Peace Creek Light, Fla.	Charlotte Harbor, Fla.	1904	*
Sneads Point Shoal Beacon	Manatee River Entrance, Fla.	1896	*
Anclote River Light No. 1	Anclote Anchorage, Fla.	1910	*
Withlacoochee River Light	Withlacoochee River Entrance, Fla.	1906	
Turning Point Light	Cedar Keys Harbor, Fla.	1899	*
Carrabelle River (3 lights)	St. George Sound, Fla.	1899, 1909 and 1913	Good
Crooked River Front Light	St. George Sound, Fla.	1913	Good
St. George Sound (4 lights)	St. George Sound, Fla.	1896, 1904 and 1913	Good
St. Andrews Bay (10 lights)	St. Andrews Bay, Fla.	1912, 1920	Good
Cobbs Point Light	Choctawhatchee Bay, Fla.	1920	Good
Santa Rosa Sound (10 lights)	Florida	1914, 1915 and 1919	Good
Pensacola Bay Range Front Light	Florida	1918	Good
Mobile Channel (22 lights)	Alabama	1905, 1917	Good
Pascagoula River Entrance (7 lights)	Mississippi	1904, 1907 and 1917	Good
Biloxi Harbor (4 lights)	Mississippi	1901	
Gulfport Channel (6 lights)	Mississippi	1910, 1916, 1918 and 1921	Good
Bayou Cork and Bayou Courant (2 lights)	Bastian Bay, La.	1917	Good
Timalier Lighthouse	Louisiana	1917	Good
Horn Island Lighthouse	Mississippi	1908	Were easily cut with cold chisel. Lower section very rusty.
Round Island Spit Lighthouse	Mississippi	1900	Metal softening. Impression can be made with file sharpened to the edge of a knife.

*All casings are 2 feet below mud line and 2 feet above mean high water. The entire underwater parts of piles were inspected by diver in August-November, 1914, and all found in good condition. The upper part of piles were last inspected during 1921-22 and some of them found to be decayed above the top of the cast iron.

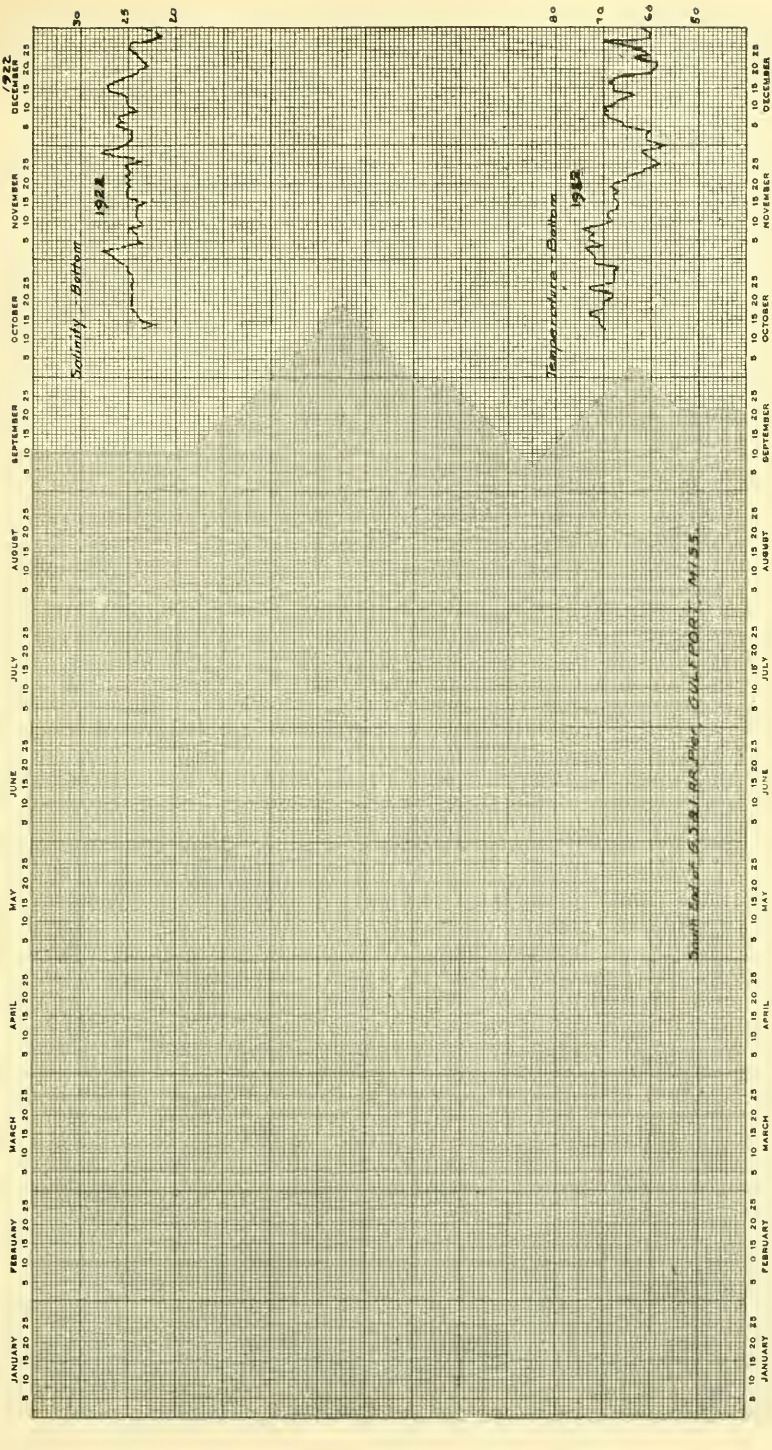


FIG. 116—SALINITY AND TEMPERATURE OBSERVATIONS (1922), G. & S. I. R.R. PIER, GULFPORT, MISS.

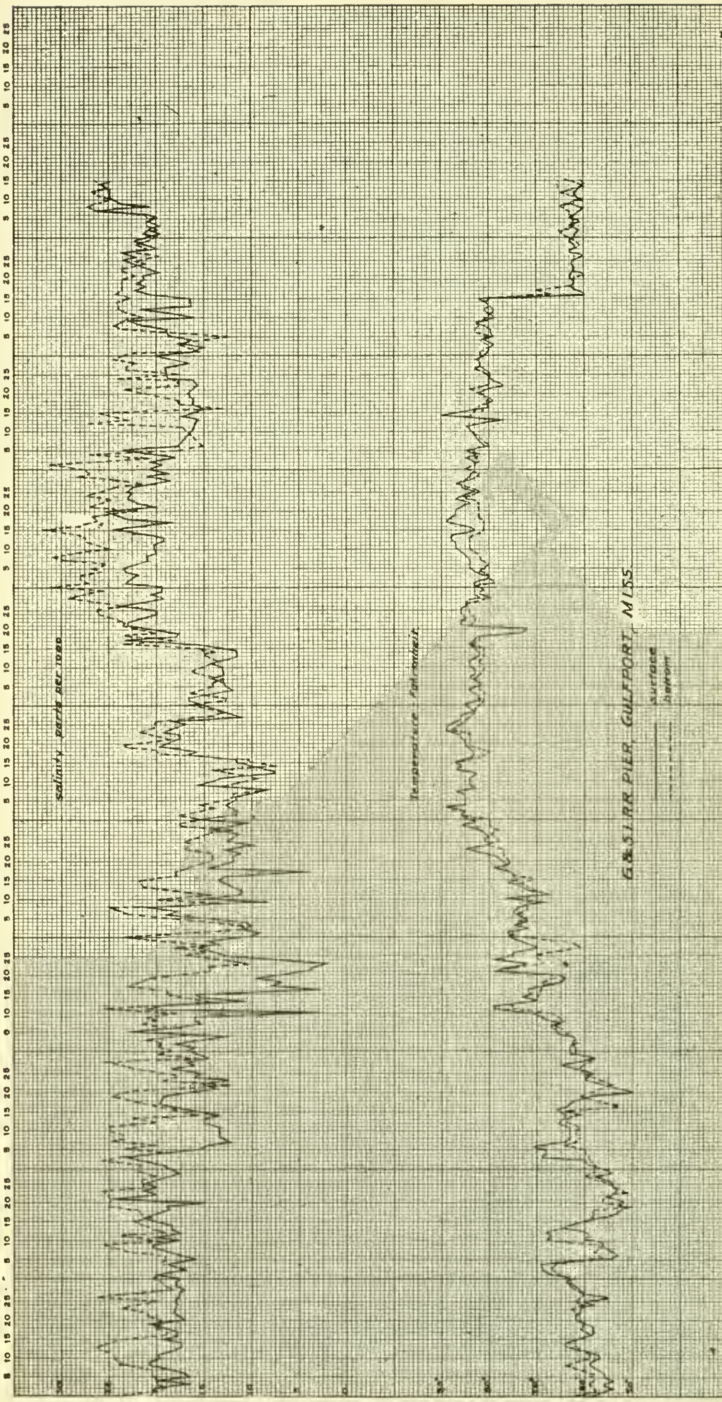


Fig. 117—Salinity and Temperature Observations (1923), G. & S. I. R.R. Pier, Gulfport, Miss.

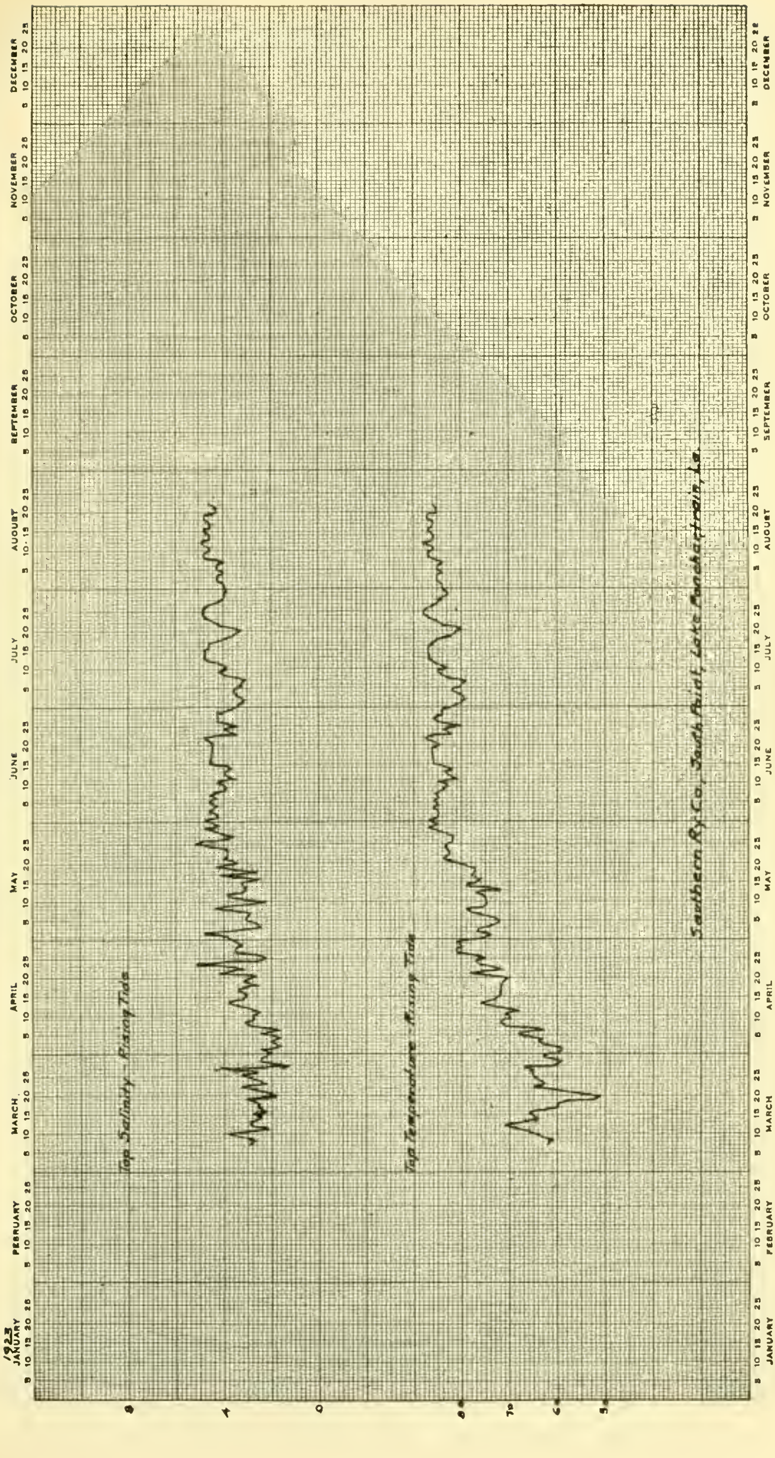


FIG. 118—SALINITY AND TEMPERATURE OBSERVATIONS, LAKE PONCHARTRAIN, LA.

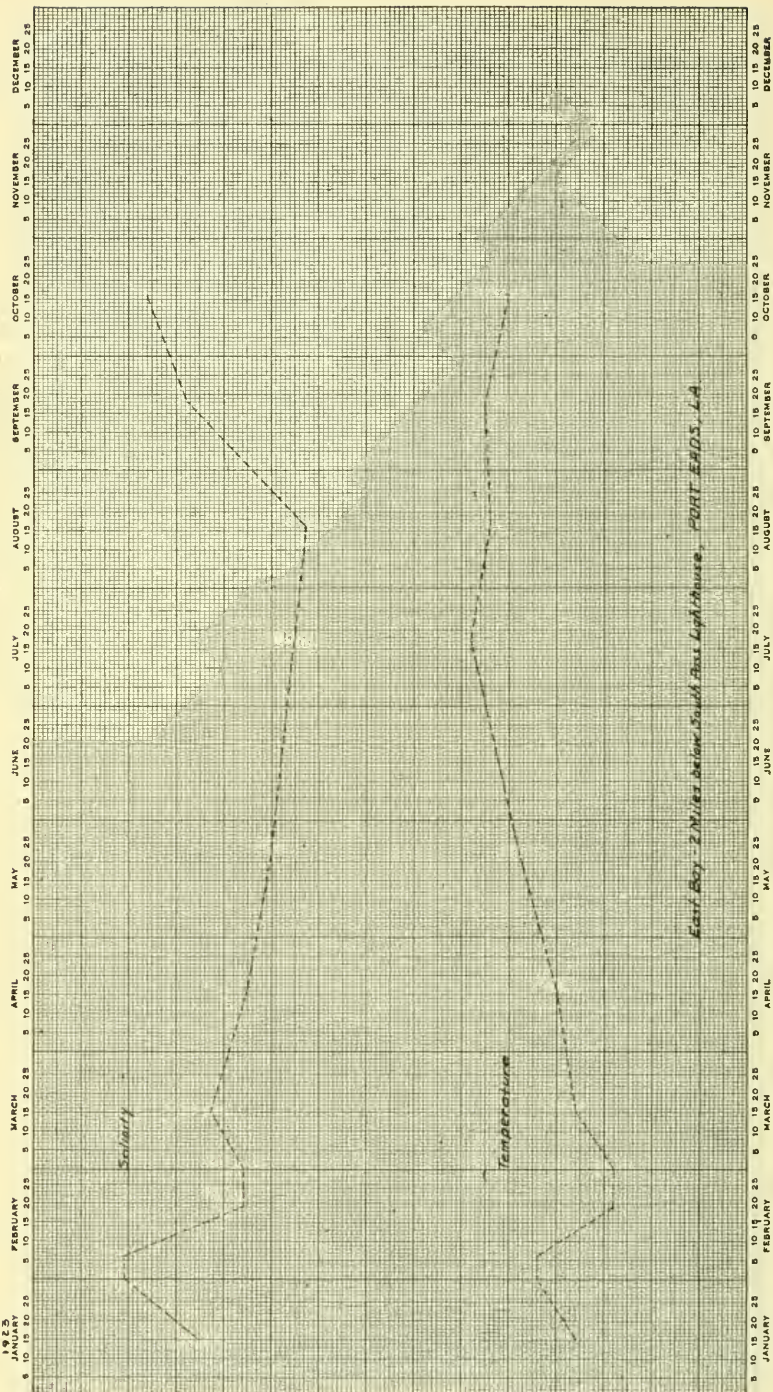


FIG. 119—SALINITY AND TEMPERATURE OBSERVATIONS, PORT EADS, LA.

Substitutes for Timber

Concrete—There is approximately 3,300 feet of docking space at the Pensacola Naval Air Station of stone and concrete, 2,100 feet of which affords a depth of 30 feet at M.L.W., the remaining 1,200 feet, a depth of 10 feet at M.L.W.; and a concrete beach along the shore line for approximately 800 feet. The main pier is constructed of concrete piling and is a recent structure. The new quay wall, connecting to the old stone and concrete quay wall, is of similar construction. The Wet Basin, constructed of stone and concrete, with a concrete bottom, affording 10 feet depth at M.L.W., was originally intended for use of the Old Spanish Drydock, which was removed to the Philadelphia Navy Yard. Both of these structures are in excellent condition, with the exception that some sand leaks have developed in the new concrete pier and quay wall on account of small openings between the sheet piles. The concrete beach protection was constructed with a concrete retaining wall on wooden piling and was completed in August, 1923.

In the year 1916 a wood bulkhead was constructed at the south end of the station. Yellow pine piles, sheet piling and wales were used, treated with 12 pounds of creosote oil per cubic foot. This structure has been completely destroyed by marine borers, and is at this time, November, 1923, being replaced with a reinforced concrete retaining wall, constructed on yellow pine untreated piles.

That part of the wooden bulkhead, to the west of and adjoining the abovementioned bulkhead, 850 feet in length and removed in the year 1922, was constructed in the year 1917 of yellow pine piles, sheet piling and wales, treated with 12 pounds of creosote oil per cubic foot and was completely destroyed by marine borers. It was replaced with a reinforced concrete retaining wall and beach, constructed on untreated yellow pine piles. Work completed August, 1923.

The fender piles on the new quay wall and pier, placed in 1920, have been considerably damaged by marine borers. Piles are yellow pine, treated with 12 pounds of creosote oil per cubic foot.

Main Pier and New Quay Wall.

Precast Piles:

Type, design, size, shape, date installed—Piling are interlocking reinforced concrete, T & G, square, installed in 1919.

Length exposed to salt water (between mud line and low water), 3 to 32 feet; between low and high water, 2 to 3 feet; above, 10½ feet.

Concrete materials—Gravel, river sand, cement, water. Std. Portland cement was utilized and fresh water used in mixing.

Reinforcement—Havemeyer square bar (steel).

Concrete mix—2:4:6 proportions, density determination used.

Curing—Conditions, length of time, season, weather. Thirty days' curing required, fresh water used in curing. Piles were kept wet.

Handling—Piles were used from 30 to 90 days after molding. They were carefully handled, only proved piles being used.

Driving—Cushion block steam hammer was used; piles were jetted also. Occasional pile rejected for hard bottom and granulated head.

Condition and description of defects or deterioration—Piling in excellent condition; concrete encasement prevents erosion. Fill seeping through piling at certain points due to conditions at various points making it impossible to get piles absolutely sand tight.

Decks and superstructures—Girders, arches, beams, slabs, walls:

Type, design, description—Wood piling and deck, protected with sand due to *Teredo* activities. Concrete top.

Exposure, height above water, wave action, spray—Exposed to from 1 to 3 feet wave action, variation of tide.

Concrete materials—Sand, gravel, cement.

Reinforcement—Steel mesh.

Mix—2:4:6.

Forms, placing of concrete—Wooden forms or framing used.

Curing—21 days.

Present condition—Excellent.

Methods of protecting concrete structures—Continuous waling and fender piling every 10 feet.

Precautions in mixing and placing—Due care was used in mixing and placing to insure proper consistency and proper placing.

Density determination used.

Waterproofing—None.

Uniting of joints, etc.—None.

Costs:

Unit costs for typical or special concrete work:

Concrete piling—$3.545 per linear foot.

Costs of methods of protection used—Creosoting, $64.77 per thousand feet.

Remarks, conclusions and recommendations: Concrete structures on the station, with the exception of the old concrete beach protected by wooden bulkhead, are in excellent condition; maintenance work has not been required to date.

Conclusions

The period of inactivity of teredine borers seems to extend from about December to April, inclusive, in most harbors along this coast, though the total cessation of growth of animals already in the wood does not seem to be as marked as in more northerly waters.

The average life of piles creosoted to refusal seems to be about 10 to 12 years.

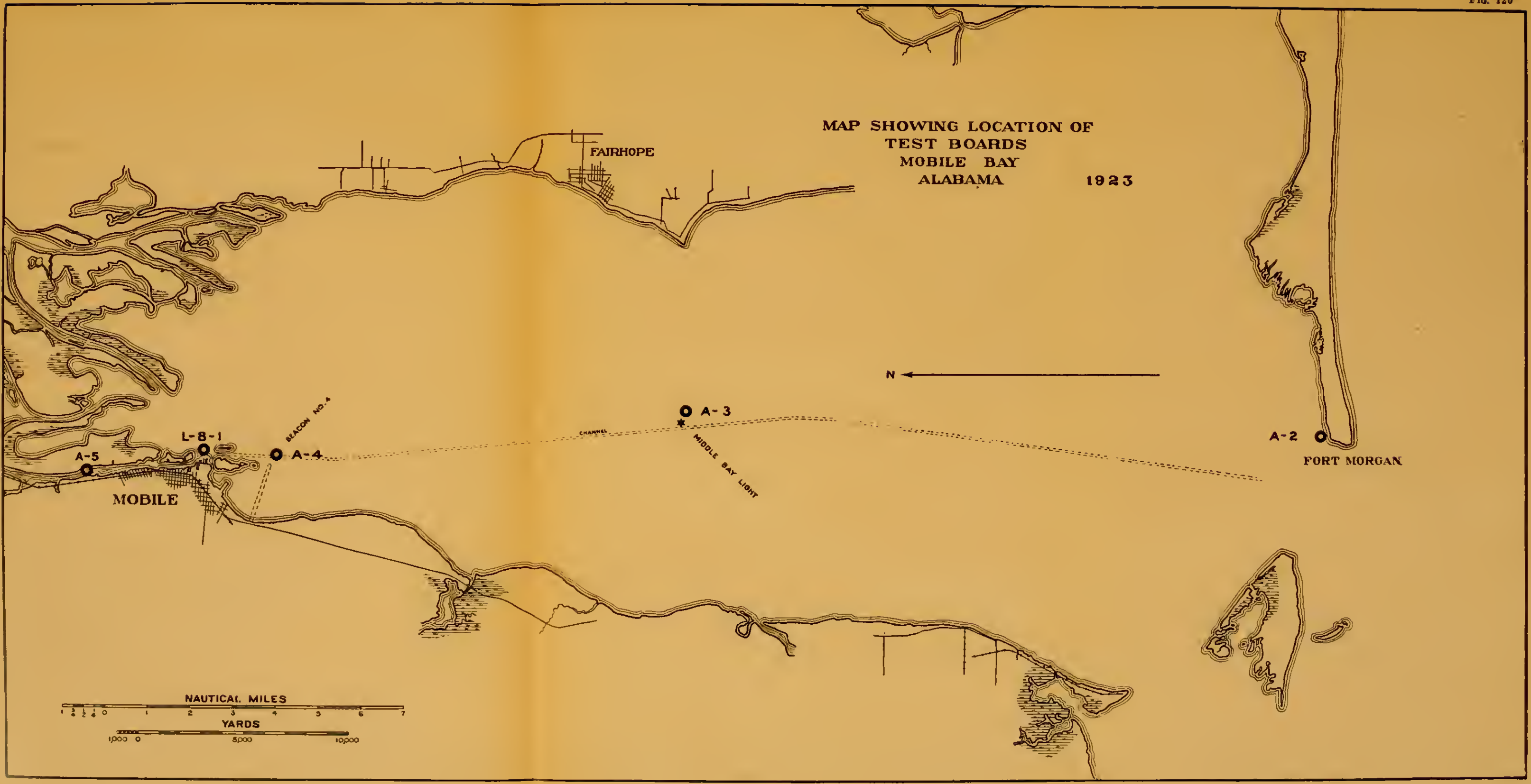
Cast iron armor as used by the Lighthouse Service and the Louisville & Nashville R. R. seems to be the most efficient method of protection if the timber is protected against decay above the iron.

The concrete structures reported are of comparatively recent construction and no conclusions regarding their probable life can be drawn.

MOBILE HARBOR

Description

Mobile Bay (Fig. 120), lies 40 miles west of Pensacola Bay entrance and 90 miles northeast of the South Pass of the Mississippi River, and is the approach to Mobile and the Alabama and Tombigbee Rivers. The entrance width between Mobile Point on the east and Dauphin Island on the west is 2¾ miles. The main ship channel across the bar has a depth of 30 feet and a minimum width of 300 feet. A dredged channel inside the entrance, having a minimum depth of 25 feet and a minimum width of 200 feet, extends


MAP SHOWING LOCATION OF
TEST BOARDS
MOBILE BAY
ALABAMA
1923
FAIRHOPE
N
A-3
CHANNEL
MIDDLE BAY LIGHT
BEACON NO. 4
L-8-1
A-4
A-5
MOBILE
A-2
FORT MORGAN
NAUTICAL MILES
0
1
2
3
4
5
6
7
YARDS
1,000
0
5,000
10,000

the length of the bay to the city of Mobile at the mouth of the Mobile River, a distance of about 25 miles.

The prevailing winds are southerly and southeasterly in spring, southerly in summer, northerly in fall, and northerly and easterly in winter; the strongest being the southerly and northerly winds of summer and winter, respectively. The range of tide varies from 3.6 feet at the entrance to the bay (Fort Morgan) to 3.4 feet in the Mobile River near the mouth of Chickasaw Creek. The currents, which vary considerably with the force and direction of the wind, have a normal velocity of 2 knots per hour in the main ship channel at the entrance, and about one-half knot per hour in the dredged channel.

Marine Borers

Past History—Up to the time of the present investigations, marine borers, both molluscan and crustacean, were known to be present at Fort Morgan. The former had been found in Mobile River up as far as Chickasabogue, but the damage to structures in the harbor proper had always been considered negligible and to require no protective measures, the piling along shore and under wharves having given no evidence of the presence of borers. The shipworms found in the river had been confined to timber lying on the bottom of the Main Ship Channel and could not be considered as conclusive evidence of local attack. However, slight attacks on the obstructions placed at the mouth of the Spanish River during the Civil War had been noticed, thus demonstrating beyond doubt the ability of the shipworm to exist in that locality. The G. M. & N. Railroad Company considered their structures (Piers No. 1 and No. 3), located at the mouth of the Mobile River, to have been immune from attack for the past twenty years.

No trace of crustacean borers had been found farther up the bay than Fort Morgan.

At Fort Morgan, the life of an unprotected pile is placed at not to exceed ninety days, whereas there is said to be piling in the river proper with sixty years' service.

Committee Investigations—Test boards of standard type were located as follows:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Fort Morgan—At entrance to Bay	A-2	Army	Oct. 1, 1922	2.0	15.0
Middle Bay Light—16 miles from entrance	A-3	Army	Oct. 13, 1922	2.0	20.3
Beacon No. 4—25 miles from entrance	A-4	Army	Oct. 10, 1922	0.0	11.9
Mobile, G. M. & N. Pier No. 3—27 miles from entrance	L-8-1	Lighthouse	Sept. 15, 1922	0.5	12.0
Mobile, U. S. Coal & Ore Wharf—30 miles from entrance	A-5	Army	Oct. 15, 1922	1.5	11.5

The results of the examination of the test blocks were as follows:

A-2—Several hundred specimens of *Bankia gouldi* were found in block 1. Succeeding blocks were well filled with *Bankia gouldi*, and destruction progressed rapidly. The old board and blocks were removed March 1, 1923, and a test board of the 1923 model was substituted. The end of the season of activity was found to have occurred some time between November 15 and

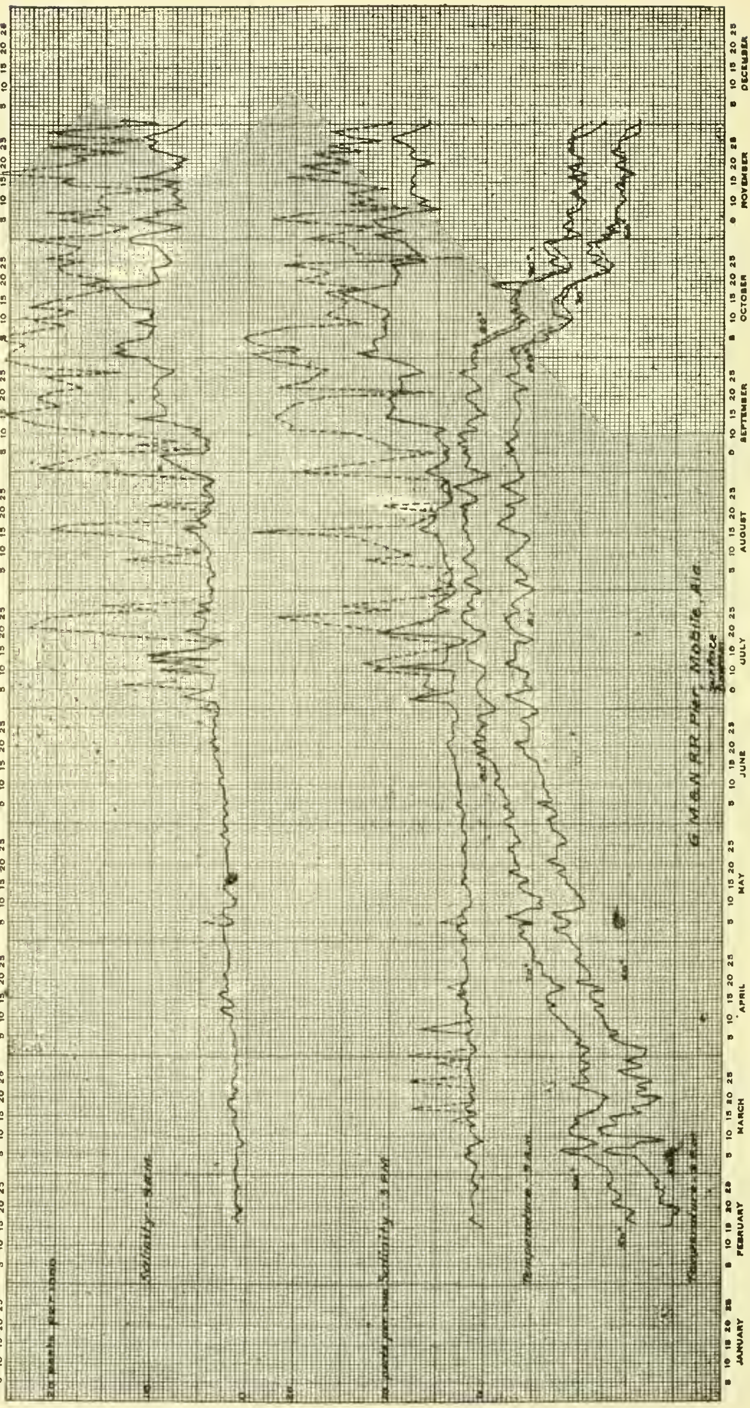


FIG. 121—SALINITY AND TEMPERATURE OBSERVATIONS, G. M. & N. R.R. PIER (LIGHTHOUSE PIER), MOBILE, ALA.

December 1. The beginning of the new season occurred between April 1 and May 1, 1923, as indicated by the absence of shipworms on block 1 and their appearance on center block 2 removed May 1, after having been in the water one month. All blocks showed *Limnoria* action of from slight to medium intensity. Two specimens of *Martesia* were found on block 9, 1922 model, removed February 15, 1923. Associated organisms were *Ostrea*, Bryozoa and *Balanus*.

A-3—*Bankia gouldi* (one specimen) first appeared on block 6, removed January 16, and was absent from succeeding blocks 7 to 10 inclusive. The reappearance of *Bankia gouldi* occurred in block 11, removed April 7. This block was well filled and block 12, removed two weeks later, was completely filled with *Bankia gouldi*. Blocks 13 to 16 inclusive contained no specimens, and blocks 19 to 23 contained from 1 to 2 specimens each of *Bankia gouldi*. It would thus appear that the blocks occupying the upper half of the board were above the level of attack. Associated organisms were *Balanus*, Bryozoa and Algae.

A-4—One specimen of *Bankia gouldi* was found in each of blocks 3 and 4, removed December 1 and 15, respectively. Block 5 contained 2 specimens, block 7 about 50, and in block 8 and all succeeding blocks, the destruction was complete. One specimen of *Martesia* was found in block 13, removed May 8. Associated organisms were *Balanus*, Bryozoa and Algae.

L-8-1—Two specimens of *Bankia gouldi* were found in block 4, removed November 16, and one in each of blocks 5 and 6; 10 to 15 were found in each of blocks 7 to 10 inclusive; about 50 were found in block 11 and about 100 in block 12. On the opposite side of the board, blocks 13 to 23 inclusive, contained each from 1 to 8 specimens of *Bankia gouldi*, and block 24 about 50. Replacement block 25, placed September 30, 1922, and removed October 1, 1923, contained no specimens. *Balanus* and Bryozoa were also present.

A-5—One shipworm only was found from the blocks of this station. This was a *Bankia gouldi*, and appeared in block 9, removed March 1, 1923. The specimen, about 20 mm. long, had been long dead. Associated organisms were *Balanus* and Bryozoa.

In addition to the above, specimens of *Bankia gouldi*, said to have been taken from fresh water, were sent in by the Alabama Dry Dock and Shipbuilding Company. This company's plant is located on the east bank of the Channel, about one mile up stream from the G. M. & N. Pier.

The season of activity of *Bankia gouldi* in this territory ended about December 1, 1922, and began somewhat later than April 1, 1923, thus providing a period of immunity of approximately four months between the dates above cited. No specimens of *Limnoria* were found above Fort Morgan, which confirms the experience of the U. S. Engineer Corps.

The heavy attack at the G. M. & N. Pier No. 3 was a complete surprise to all concerned, as the salinity of the water at that point is much below what has hitherto been considered requisite for the continued existence of this species (*Bankia gouldi*) of shipworm. As soon as the first organism made its appearance, therefore, salinity observations were deemed advisable, and have been made twice daily of both surface and bottom samples, beginning January 6, 1923. The results of these observations are shown on Fig. 121.

Methods of Protection

Creosote impregnation (20 pounds per cubic foot) is employed by the Corps of Engineers, U. S. A., for all timber exposed to the attack of marine

borers at Fort Morgan. Timber so treated is said to last from eight to ten years.

Pier No. 3 of the G. M. & N. Railroad Company mentioned above is constructed of untreated timber, the piles being capped at from six to eight inches below mean low water. Pier No. 1 of the same company is supported by creosoted piles, the impregnation being 18 pounds per cubic foot.

Further information on methods of protection will be found in the report on Gulf of Mexico—Mississippi River to Key West.

Conclusions

Unprotected timber in the Mobile River should have an expected life of from five to ten years unless dry weather causes a continued comparatively high salinity, when destruction may be rapid.

At Fort Morgan, the rate of destruction is much more rapid, a single season being sufficient time in which to destroy unprotected timber.

Piles at Fort Morgan should have the best protection that can be devised, and protection is certainly needed to the mouth of the river. Owing to the variable salinity conditions in the river and consequent liability to attack, it would seem wise to protect all piles under important structures for a distance of at least 28 miles above Fort Morgan.

GULF OF MEXICO—SABINE PASS TO POINT ISABEL

General Description

This report covers the harbors of Sabine Pass, Port Arthur, Galveston, Houston Ship Channel, Rockport, Port Aransas, Corpus Christi and Point Isabel—all in the State of Texas.

The coast line throughout the territory is generally sandy, and the entrances to the harbors are obstructed by shifting sand bars over which the channel depths are changeable. Most of the entrances are being improved by dredging, and in some cases jetties to maintain or increase the present depths have been built. The tidal currents have considerable velocity in all of the entrances, and their direction is affected by the force and direction of the wind.

Sabine Pass (Fig. 122), 50 miles northeastward of Galveston entrance, is the approach to Port Arthur, Orange and Beaumont. There is a dredged channel 28 feet deep and 100 feet wide between jetties. The mean rise and fall of tide is 1.5 feet.

Port Arthur (Fig. 122) is located on the west shore of Sabine Lake, and has deep water connection with Sabine Pass by means of the Port Arthur Ship Canal to Taylor Bayou, and by the Sabine-Neches Canal along its southeast point, the controlling depth being 26¾ feet. The mean rise and fall of the tide at the site of the test boards is 1.0 foot.

Galveston Harbor (Fig. 123) is divided into two parts, Bolivar Roads and Galveston Channel. From Bolivar Roads, which is the deep water way between Bolivar Point and Pelican Island, there is a dredged channel 200 feet wide and 24 feet deep to Port Bolivar, a terminal of the Gulf, Colorado and Santa Fe Railroad, about four miles north of Galveston. Galveston Channel is a dredged channel 30 to 35 feet deep and 1,000 to 1,200 feet wide, extending for about 3½ miles from Bolivar Roads southwestward and westward, past Fort Point and the northwestern end of Galveston Island and along the

northern waterfront of the City of Galveston. The mean rise and fall of tide is 1.6 feet at Fort Point and Pier 18.

Houston Ship Channel (Fig. 124) extends from Galveston Harbor across Galveston Bay and through parts of San Jacinto River and Buffalo Bayou to the city of Houston, a distance of 50 miles. The canal has been dredged to a depth of 25 feet in a channel 100 feet wide for 44 miles to the turning basin, 6 miles below Houston. As will be noted in the biological section of this report, shipworms have been found in this channel at a point midway between Lynchburg and Clinton, a distance of about 35 miles from Galveston.

Aransas Pass (Figs. 125 and 126) lies 154 miles southwest of Galveston entrance and 113 miles north of the mouth of the Rio Grande. It is the principal approach to Aransas and Corpus Christi Bays. The depth of water through the pass is 24 feet with a channel width of 100 to 400 feet. A dredged channel 11 feet deep extends from the inner end of the Pass to Port Aransas. Rockport is on the west shore of Aransas Bay and there is a depth of 7 feet at wharves. Corpus Christi is on the western side of Corpus Christi Bay, 18 miles from Aransas Pass. A dredged channel 100 feet wide and 12 feet deep extends from the deep water in the bay to a turning basin 1,000 feet square, off the wharves. The mean rise and fall of tide at Aransas Pass is 2.0 feet.

Point Isabel (Fig. 127) is 2¼ miles west of the entrance to Brazos Santiago, and about 7 miles north of the mouth of the Rio Grande. The mean rise and fall of tide is 2.0 feet.

Marine Borers

Past History—Both shipworms and crustacean borers have been known to exist throughout this territory, except in the fresh water portions of the dredged channels. The life of unprotected piling is estimated to be from three to six months in the summer season at Galveston; four months at Sabine Pass, and five to twelve months at Aransas Pass, depending on the season of the year when driven.

Committee Investigations—Standard test boards were installed as shown in the table on page 366.

Results of these tests to date are as follows:

A-8—*Bankia gouldi* first appeared in block No. 3, removed October 15, 1922, the previous blocks having numerous barnacles. An average of about 20 specimens of *Bankia gouldi*, some of them 10 inches long, was found in each of the succeeding blocks, including block 12, removed March 1, 1923, when a new type board was substituted. The end of the season of activity occurred between November 1 and 15, 1922. Center block 5 of the new board contained the first specimens (about 30) of the new brood of *Bankia gouldi*. This block was removed August 15, 1923, after being exposed one month. The longest tubes noted were about 20 mm. but in the following month 200 animals up to 6 inches in length were found, and this length had increased to 9 inches by October 15. Associated organisms were *Balanus*, some Bryozoa and Algae.

KCS-1 and 2—Twenty-six blocks from each of these boards have been examined. No life of any kind was found.

A thorough investigation of this territory was made by the Texas Oil Company. Its report states that up to about 1900, shipworms were very de-

structive. The Kansas City Southern Railroad docks, built in 1897-1898, were found to be badly damaged in 1901 and had to be redriven. Since that time the borers have practically disappeared from the turning basin but not from the remainder of the canal.

A similar investigation in the harbor of Beaumont showed no evidence of serious borer attack, though a small amount of evidence was found of the occasional presence of a few shipworms.

SP-1—Attack began immediately, the first block showing about 200 young shipworms to the square inch. In succeeding blocks identification was made of *Teredo bartschi* and *Bankia gouldi*, the latter appearing in the proportion of about 1 to 100 specimens of *Teredo bartschi*. The destruction was so rapid that it was necessary to replace the board with a metal bar. All the original and replacement blocks were removed April 1, 1923, and sent in for inspection. New blocks of revised type were attached at the same time. The end of the season of activity was found to have occurred between November 1 and 15. The first shipworms (about 100) to appear on the new blocks were found in block 2, removed June 1, 1923, after being in the water one month; after this time the rate of destruction was very high. Heavy damage by *Limnoria* occurred. Other organisms were *Balanus* and Bryozoa.

A-7—Shipworms appeared on block 1 but were not so plentiful as at SP-1. Destruction was severe but did not progress as rapidly as at SP-1. The majority of shipworms in the first blocks were *Bankia gouldi*, but in succeeding blocks *Teredo bartschi* was far more numerous, averaging about 80 per cent of the total. The old board was replaced by the new type May 1, 1923. The end of the season of activity was found to have occurred about December 31, 1922, and the period of immunity lasted until May 1, 1923. Of the new blocks, *Bankia gouldi* first appeared on block 1, removed June 1, 1923, after having been exposed one month. *Bankia gouldi* showed exceedingly rapid growth at this station, center block No. 4, removed September 1, after one month's immersion, containing animals 2 to 3 inches long. Block 4, removed September 1, 1923, after 4 months' exposure, was completely destroyed. Up to that date no specimens of *Teredo bartschi* had been found. *Limnoria* was not numerous in these blocks. Associated organisms were *Balanus*, Bryozoa and Anomia.

A-6—The rate of destruction was greater than that at A-7, and about the same as at SP-1. Both *Bankia gouldi* and *Teredo bartschi* were found, the former in far greater numbers than the latter. A period of immunity from *Bankia gouldi* from January 1 to May 1 was established. A new board of the 1923 model was substituted for the original one May 1, 1923. *Bankia gouldi* appeared on the first block, removed June 1, 1923. No specimens of *Teredo bartschi* have been found to date (October 1, 1923). Associated organisms were *Balanus*, Bryozoa and Ostrea.

SF-1—Destruction was more rapid here than at any other point under observation. All specimens examined were *Bankia gouldi*, and complete destruction was accomplished in six weeks' time. Associated organisms were *Balanus*, Bryozoa and Ostrea. One young specimen of *Martesia* was found.

PH-1—*Bankia gouldi* first appeared in block 7, removed February 1, 1923. None appeared in succeeding blocks until No. 16 was removed (June 17, 1923), which contained one specimen. Associated organisms were *Balanus* and Bryozoa. A bulkhead at this point was completely destroyed by *Bankia gouldi* in 1908-1909.

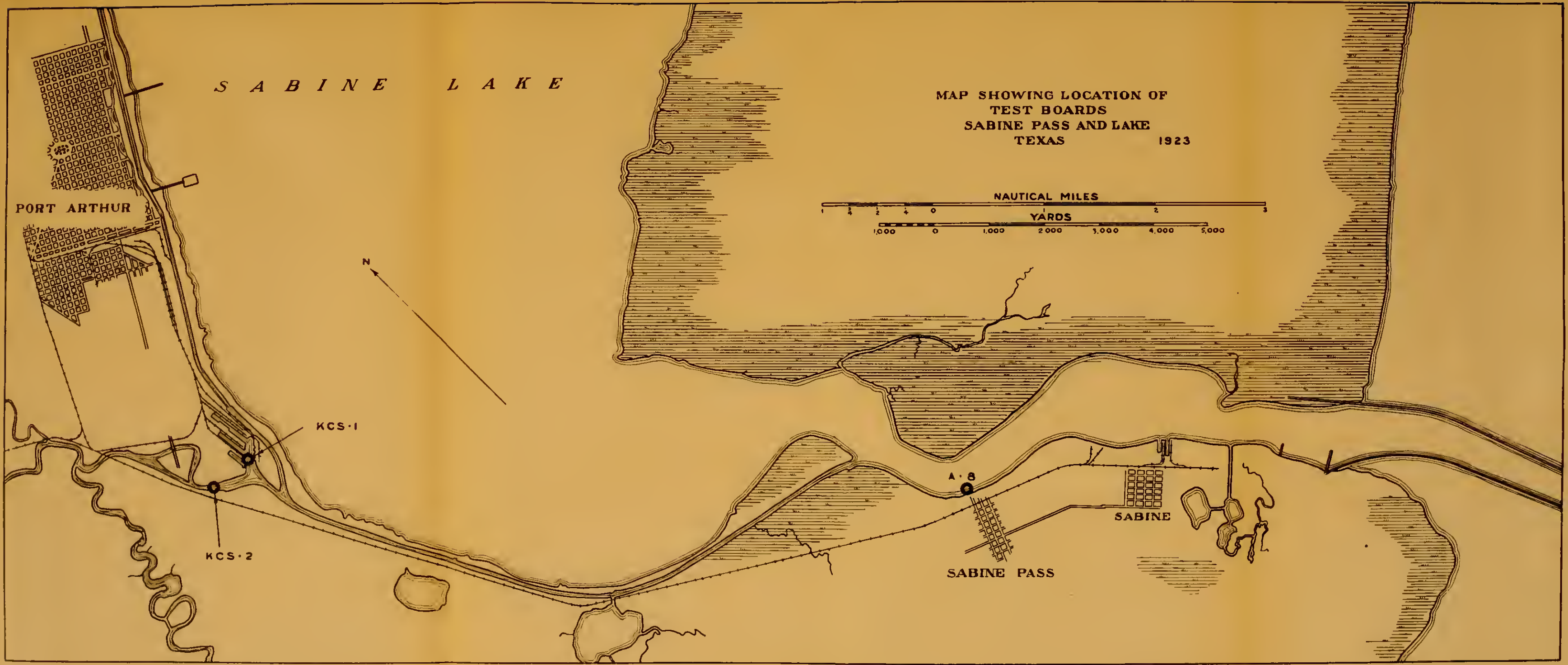
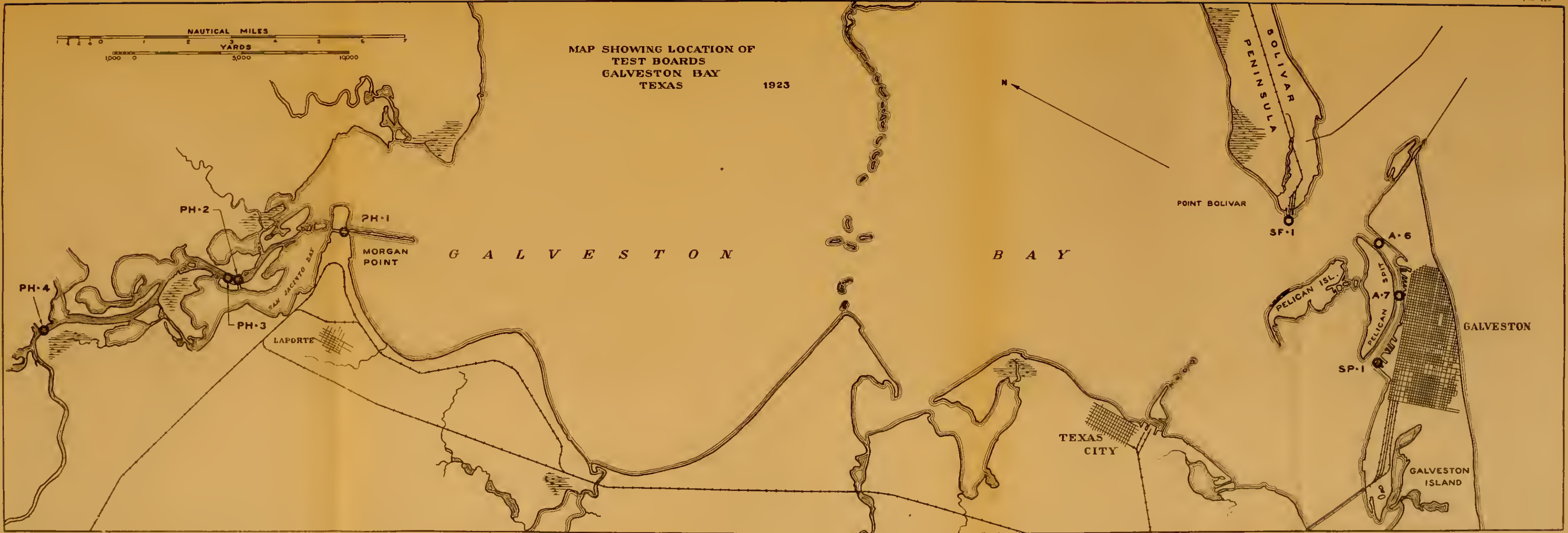
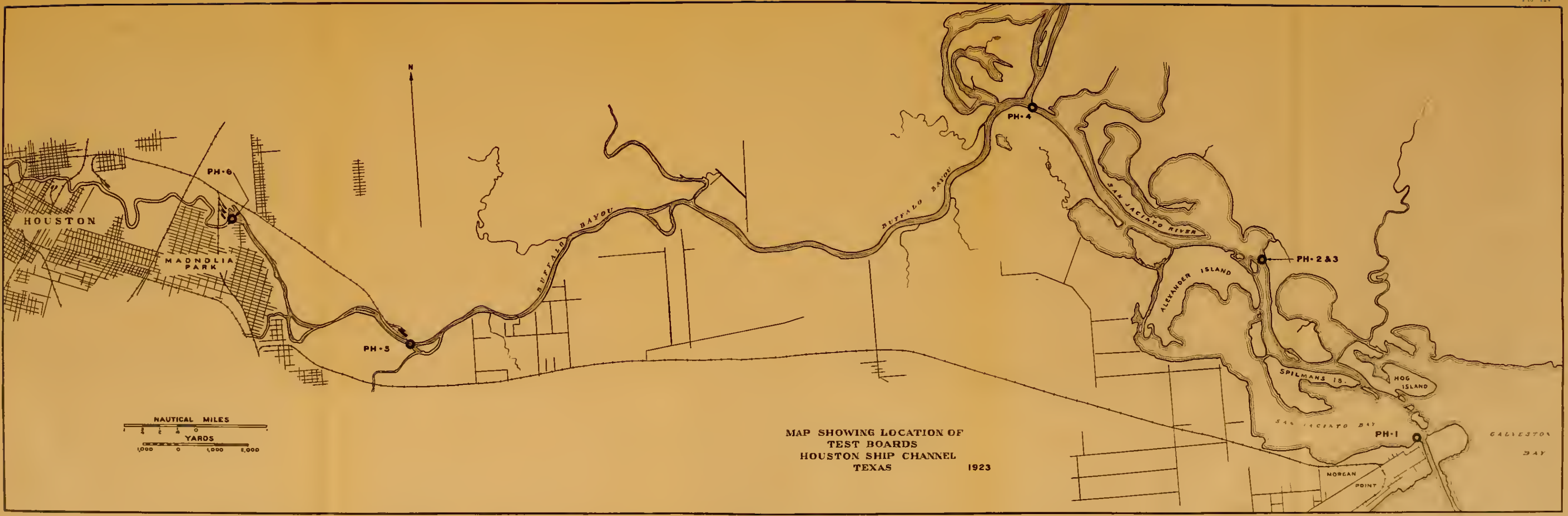

SABINE LAKE
MAP SHOWING LOCATION OF
TEST BOARDS
SABINE PASS AND LAKE
TEXAS 1923
NAUTICAL MILES
YARDS
PORT ARTHUR
N
KCS·1
KCS·2
A·8
SABINE
SABINE PASS

FIG. 123


MAP SHOWING LOCATION OF
TEST BOARDS
GALVESTON BAY
TEXAS
1923
NAUTICAL MILES
YARDS
1,000
0
5,000
10,000
N
BOLIVAR
PENINSULA
POINT BOLIVAR
SF·1
PH·1
PH·2
PH·3
PH·4
MORGAN
POINT
SAN JACINTO BAY
LAPORTE
G A L V E S T O N
B A Y
A·6
A·7
SP·1
PELICAN ISL.
PELICAN SPIT
GALVESTON
TEXAS
CITY
GALVESTON
ISLAND



MAP SHOWING LOCATION OF TEST BOARDS HOUSTON SHIP CHANNEL TEXAS 1923

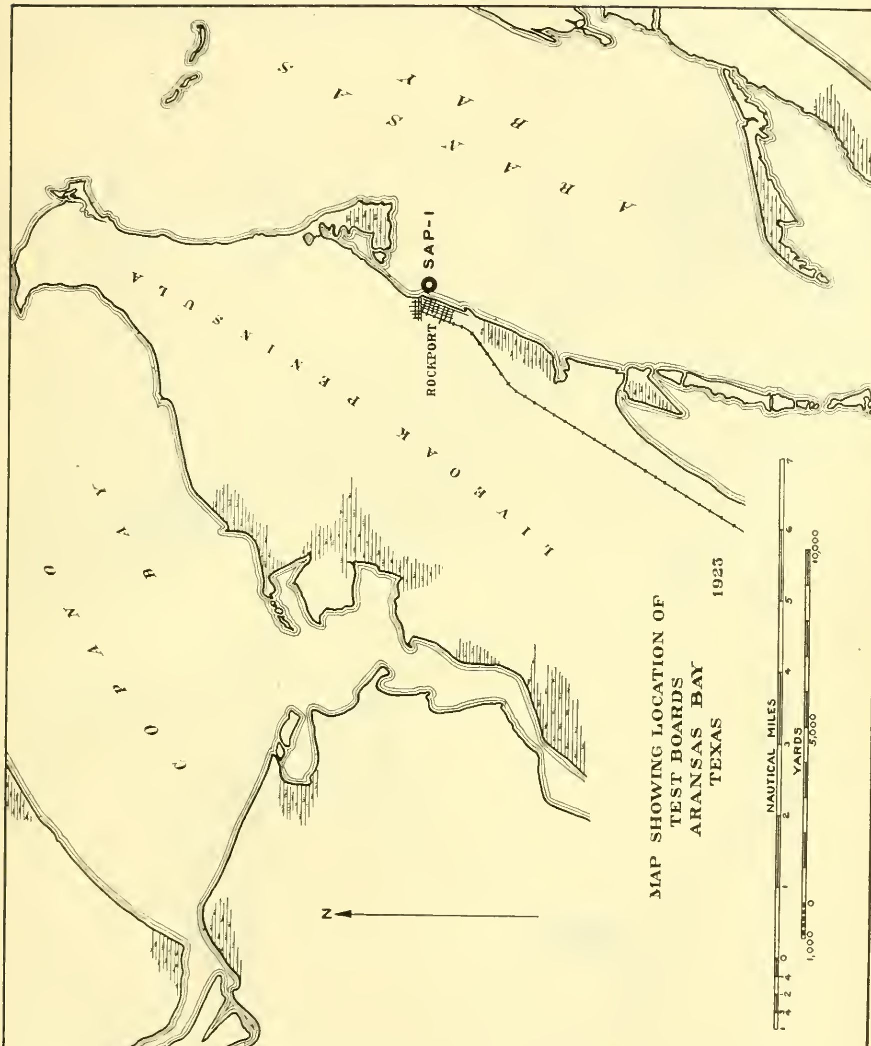

ARANSAS BAY
SAP-1
ROCKPORT
LIVE OAK PENINSULA
COPANO BAY
N
MAP SHOWING LOCATION OF
TEST BOARDS
ARANSAS BAY
TEXAS
1923
NAUTICAL MILES
YARDS

FIG. 125

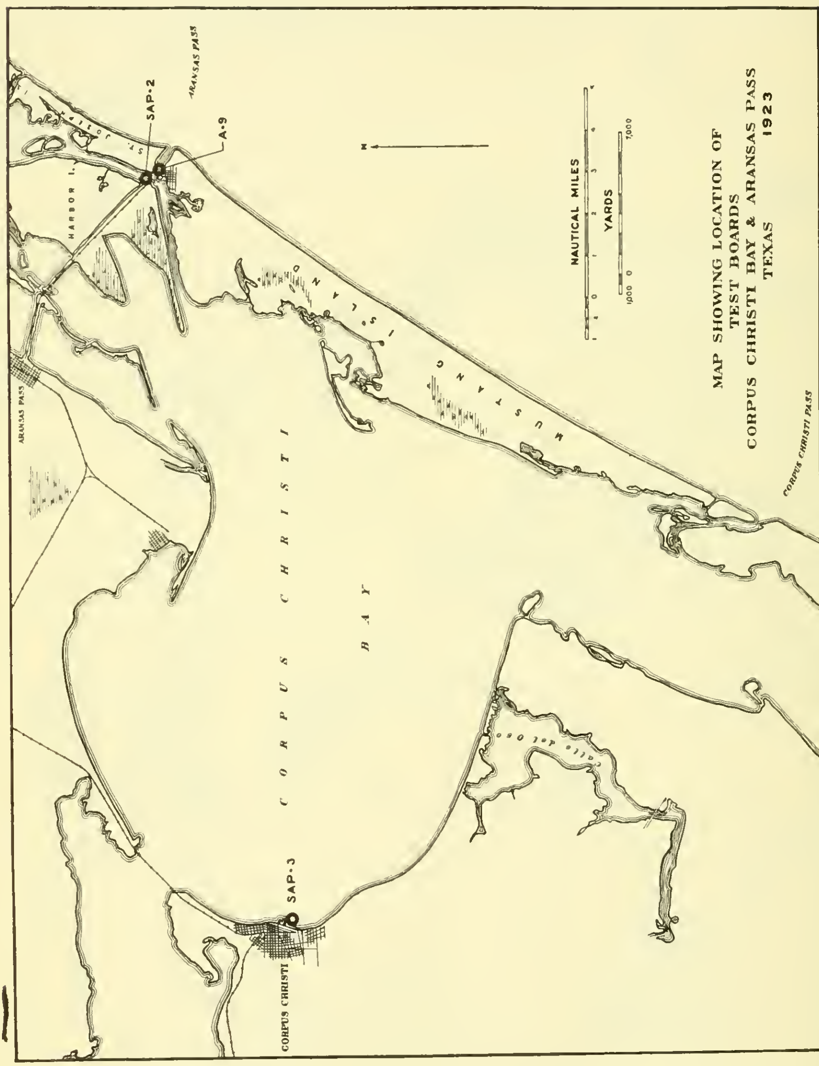

MAP SHOWING LOCATION OF
TEST BOARDS
CORPUS CHRISTI BAY & ARANSAS PASS
TEXAS
1923
NAUTICAL MILES
YARDS
SAP-2
A-9
SAP-3
ARANSAS PASS
HARBOR I.
ARANSAS PASS
CORPUS CHRISTI
CORPUS CHRISTI
BAY
MUSTANG ISLAND
CORPUS CHRISTI PASS
Cayo del Oso

FIG. 126

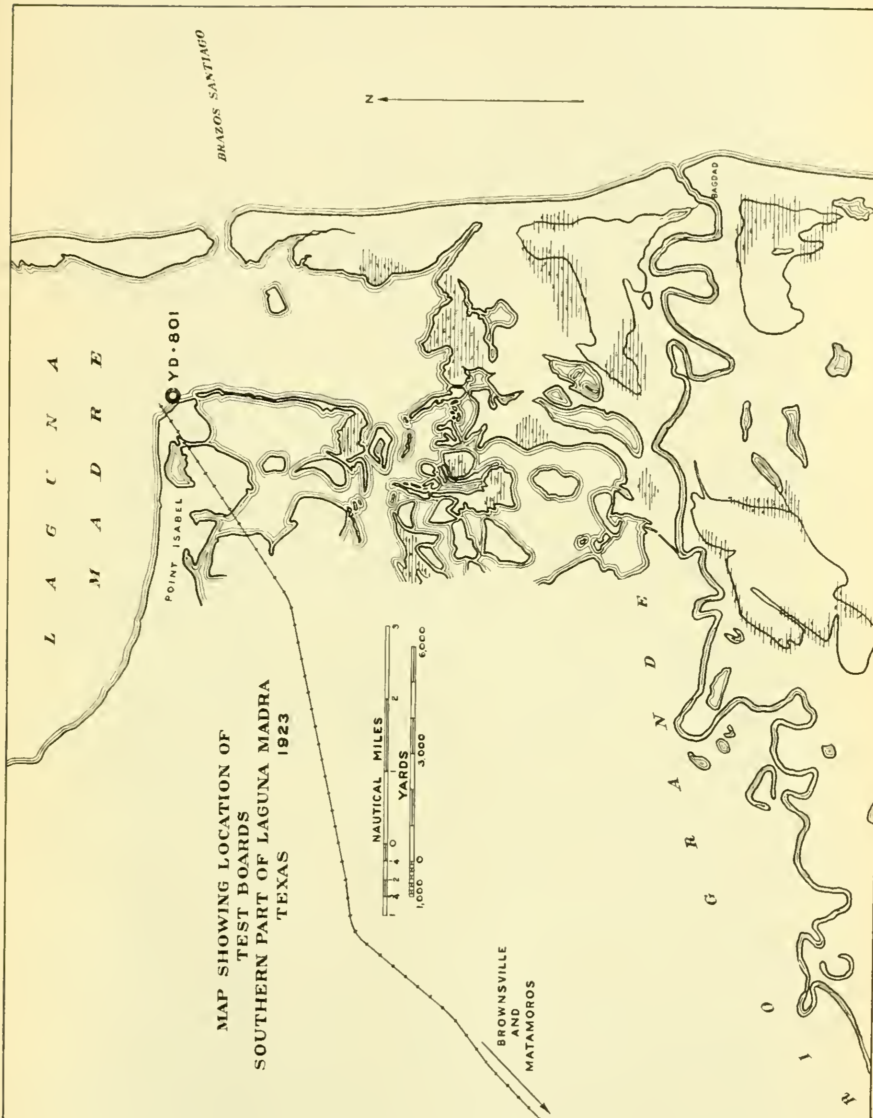

MAP SHOWING LOCATION OF
TEST BOARDS
SOUTHERN PART OF LAGUNA MADRA
TEXAS 1923
LAGUNA
MADRE
BRAZOS SANTIAGO
N
YD-801
POINT ISABEL
BAGDAD
RIO GRANDE
NAUTICAL MILES
YARDS
BROWNSVILLE
AND
MATAMOROS

Fig. 127

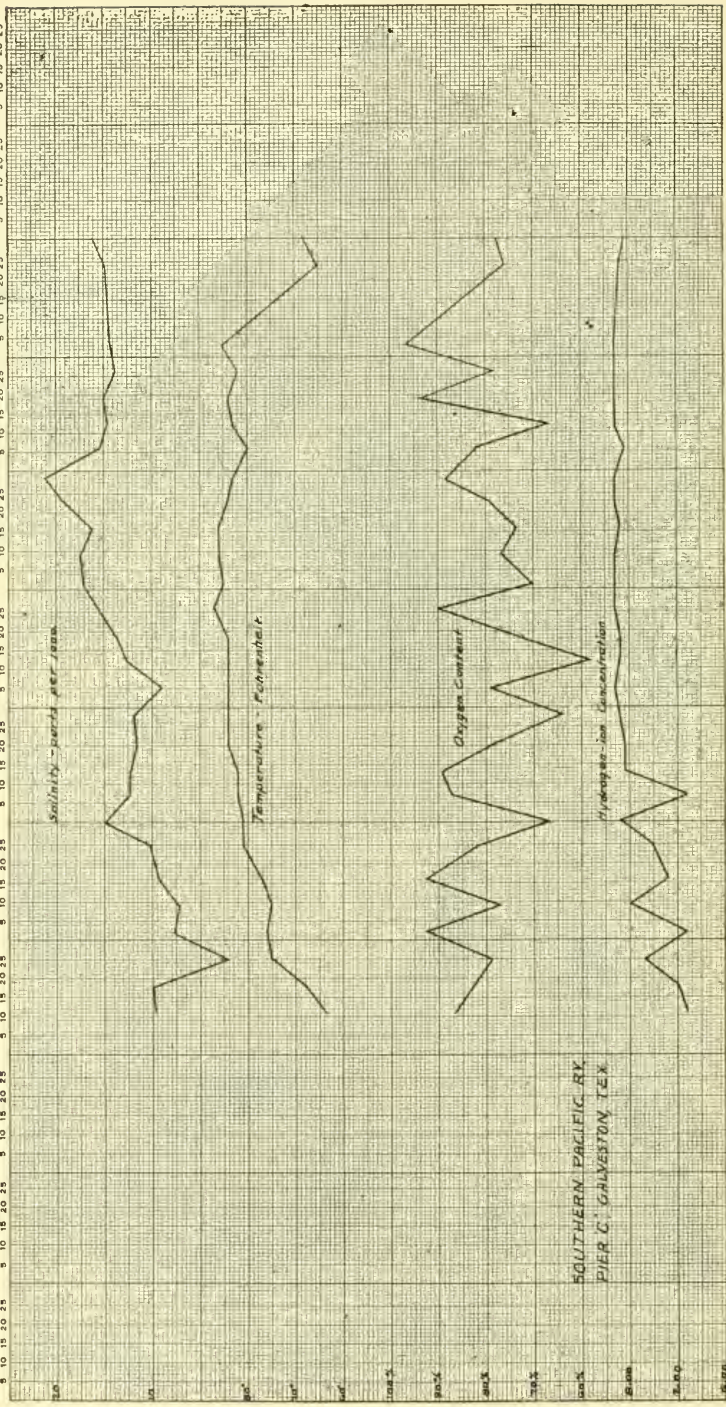


FIG. 128—SALINITY, TEMPERATURE, OXYGEN CONTENT AND HYDROGEN-ION CONCENTRATION OF THE WATER AT SOUTHERN PACIFIC RAILWAY PIER C, GALVESTON, TEXAS

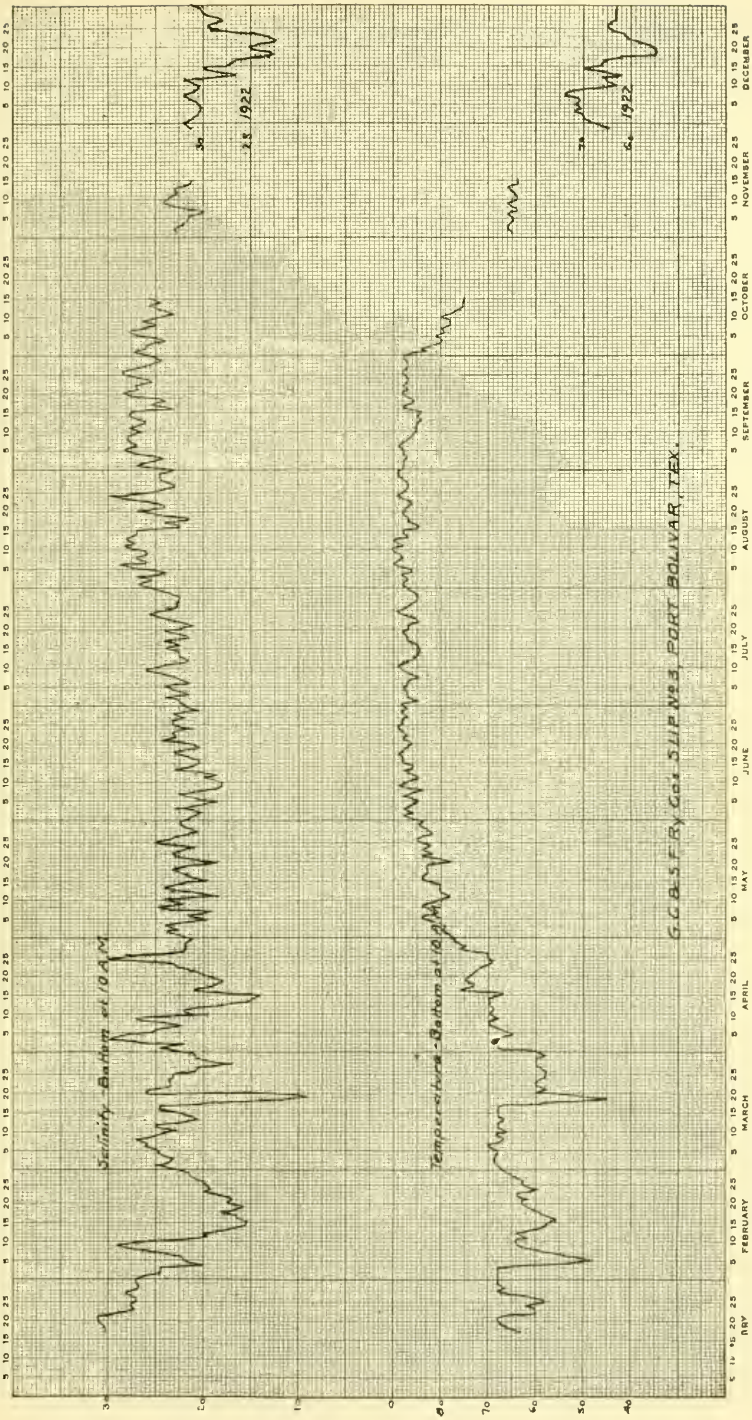


FIG. 129—SALINITY AND TEMPERATURE OBSERVATIONS, G. C. & S. F. RY. CO.'S SLIP NO. 3, PORT BOLIVAR, TEX.

PH-2—*Bankia gouldi* first appeared on block 2, removed October, 1922. From 50 to 100 specimens were found in succeeding blocks, including No. 11, removed February 15, 1923, and destruction was almost complete. One specimen of *Teredo bartschi* was found in the old board. A 1923 model board was substituted March 1, 1923. No shipworms were found on blocks removed as late as August, 1923. Associated organisms observed were *Balanus* and Ostrea.

PH-3—The attack during the season of 1922 was similar to that on PH-2, but no new board was placed in 1923.

PH-4—A large number of specimens of *Balanus* was the only life found. A specimen of mulberry timber from the hull of a sunken schooner in place twenty years at this point showed a light attack by *Bankia gouldi.*

PH-5—No life of any kind. A section of a pine pile from an old wharf located about half way between this point and PH-4 was found to contain a single specimen of *Bankia gouldi.*

PH-6—No life of any kind. A single analysis made of the water at this point November 21, 1922, showed no salt.

SAP-1—*Bankia gouldi* was first found in block 6, removed January 1, 1923. Many hundreds of dead shipworm larvae were found in block 8, removed February 1, 1923. The block contained about 20 mature specimens, both *Bankia gouldi* and *Teredo bartschi,* with tubes up to 4 inches in length. This board was lost, and consequently no date of ending of the season of activity could be established. A new board of revised type was installed April 1, 1923. The first appearance of *Bankia gouldi* was in center block 2,

Test Boards, Sabine Pass to Point Isabel

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Sabine Pass, Texas	A-8	Army	....	0.5	15.0
Port Arthur, Texas—Slip No. 3	KCS-1	Kansas City Southern R. R.	June 15, 1922	0.1	13.4
Port Arthur, Texas—Texas Co Wharf	KCS-2	Kansas City Southern R. R.	June 15, 1922	0.2	14.9
Galveston, Texas—Pier C	SP-1	Southern Pacific R. R.	Aug. 1, 1922	7.0	9.0
Galveston, Texas—Pier 18	A-7	Army	Sept. 1, 1922	6.9	9.6
Galveston, Texas—Fort Point	A-6	Army	Sept. 1, 1922	1.0	8.2
Galveston, Texas—Port Bolivar	SF-1	Gulf, Colorado & Santa Fe R. R.	July 1, 1922	......	......
Houston Ship Channel—					
Morgan Point—Galveston Bay	PH-1	Port of Houston	Oct. 16, 1922	1.0	6.5
Baytown—4 miles above Morgan Point	PH-2	Port of Houston	Sept. 1, 1922	1.0	17.0
Baytown—4 miles above Morgan Point	PH-3	Port of Houston	Sept. 1, 1922	1.0	14.5
Gulf Pipe Line Wharf—8 miles above Morgan Point	PH-4	Port of Houston	Nov. 16, 1922	......	......
Sinclair Oil Co.—19 miles above Morgan Point	PH-5	Port of Houston	Sept. 1, 1922	1.0	9.0
Turning Basin, Houston—22 miles above Morgan Point	PH-6	Port of Houston	Oct. 1, 1922	......	......
Rockport, Texas—S. A. P. Wharf	SAP-1	San Antonio & Aransas Pass R. R.	Oct. 1, 1922	......	......
Port Aransas, Texas	SAP-2	San Antonio & Aransas Pass R. R.	Oct. 1, 1922	......	......
Aransas Pass, Texas	A-9	Army	Sept. 1, 1922	1.0	9.2
Corpus Christi, Texas	SAP-3	San Antonio & Aransas Pass R. R.	Oct. 1, 1922	......	......
Point Isabel, Texas	YD-801	Navy	Oct. 31, 1922	1.0	*4.0

*Board suspended in a horizontal position.

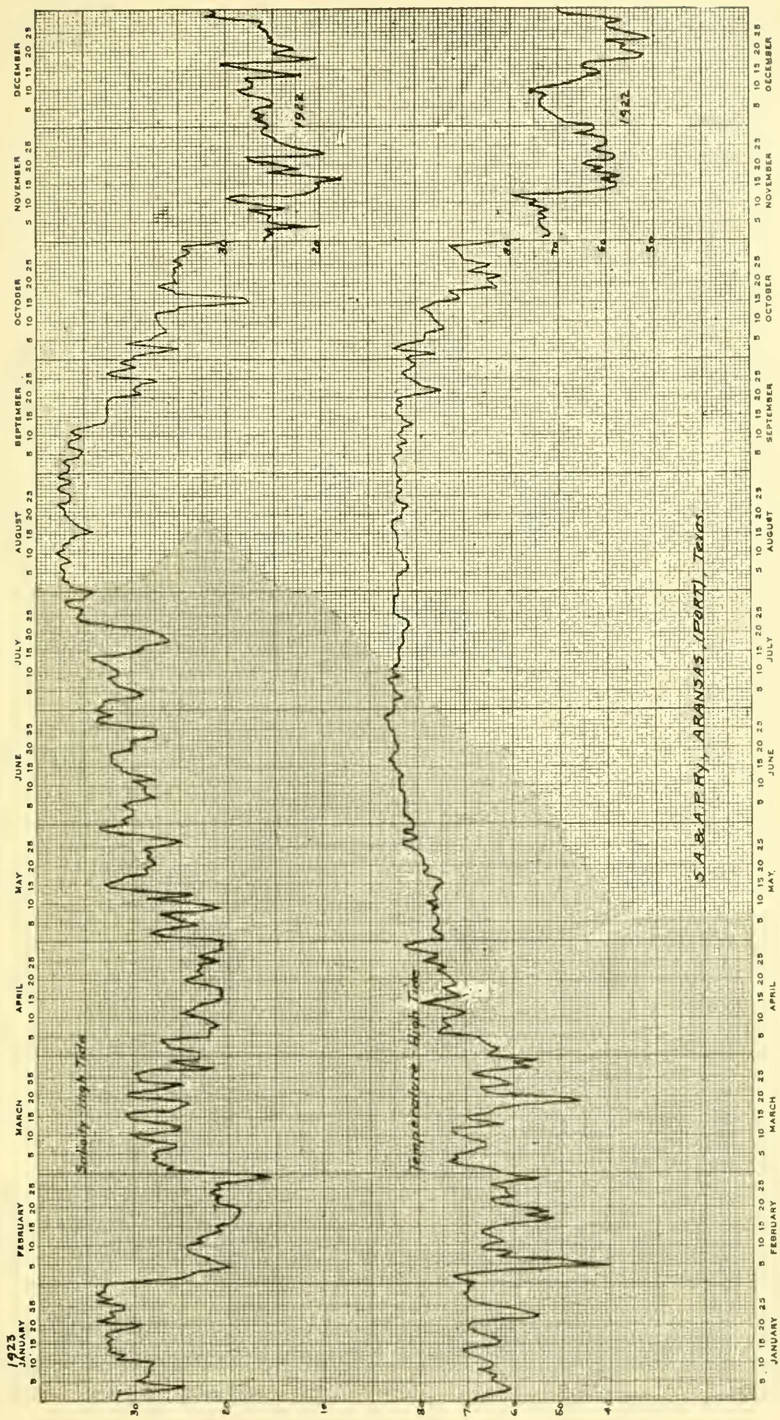


FIG. 130.—SALINITY AND TEMPERATURE OBSERVATIONS, S. A. & A. P. RY. PIER, PORT ARANSAS, TEX.

removed June 1, 1923, after having been in water one month. No specimens of *Teredo bartschi* have been found to date (August 1). Associated organisms were *Balanus* and Bryozoa (*Lepralia*).

SAP-2—*Bankia gouldi* first appeared in block 2, removed October 15, 1922, and destruction progressed rapidly. A few specimens of *Teredo sp. J* were found in subsequent blocks. A new board of the 1923 model was installed April 1, 1923, the old board having been lost. The first *Bankia gouldi* appeared in center block 2, removed June 1, after being in water one month, but since specimens over 4 inches long were found in block 2, which had been immersed two months, it is probable that the attack started in April. The first *Teredo sp. J* appeared in September in large numbers. The damage by *Limnoria* was inconsiderable. Associated organisms were *Balanus*, Bryozoa (encrusting and branching), Ostrea and Anomia.

A-9—Shipworms appeared in the first block, removed September 15, 1922, and destruction proceeded rapidly. In the first blocks specimens of *Teredo* outnumbered those of *Bankia*, but the *Bankia* grew much more rapidly, reaching a length of 4½ inches in one month. This condition as to number, however, was reversed in later blocks. *Teredo bartschi, Teredo sp. J*, and *Bankia gouldi* were identified. The old board was replaced March 1, 1923, by one of the 1923 model. The end of the season of activity was found to have occurred between December 15, 1922, and January 1, 1923. *Bankia gouldi* was found in center block 2, of the new board, in water one month and removed April 30, 1923. *Teredo sp. J* appeared in the block removed October 1, 1923. *Limnoria* action was severe, and some specimens of *Martesia* were found. Associated organisms were *Balanus*, Bryozoa, Ostrea and Algae.

SAP-3—About 100 specimens of *Bankia gouldi* appeared in block 2, removed October 31; *Teredo bartschi* in the next block two weeks later. Specimens of *Teredo bartschi* were far more numerous than those of *Bankia gouldi* in blocks from this station. The end of the season of activity appears to have occurred about October 15, as no larvae were found after that date. The destruction was complete and the board was replaced by one of revised type, April 1. No shipworms had appeared up to May 1, 1923, shortly after which date the new board was lost. Associated organisms were *Balanus* and encrusting Bryozoa.

YD-801—Shipworms, mostly *Bankia gouldi*, appeared in the first block, removed November 16, 1922, and destruction proceeded rapidly. A few specimens of *Teredo sp. J* and *sp. Q* were found. The board was lost February 16, 1922. A new board of revised type was installed April 13, 1923, and the first blocks, removed one month later, were well filled with *Bankia gouldi* with tubes averaging 20 mm. *Teredo sp. J* was first found in center block 4, removed August 13, after one month in the water; the center block, removed October 15, contained several hundred.

It will be noted from the above that a period of immunity from shipworm attack existed at Sabine Pass extending from November 15, 1922, to about July 1, 1923; at Galveston from January 1 to May 1; at Aransas Pass from January 1 to April 15, and at Corpus Christi from October 15 to about May 1.

Salinity and temperature observations, and tests for oxygen content and hydrogen-ion concentration of the water at Pier C, Galveston, were recorded by the Southern Pacific Company. Salinity and temperature observations

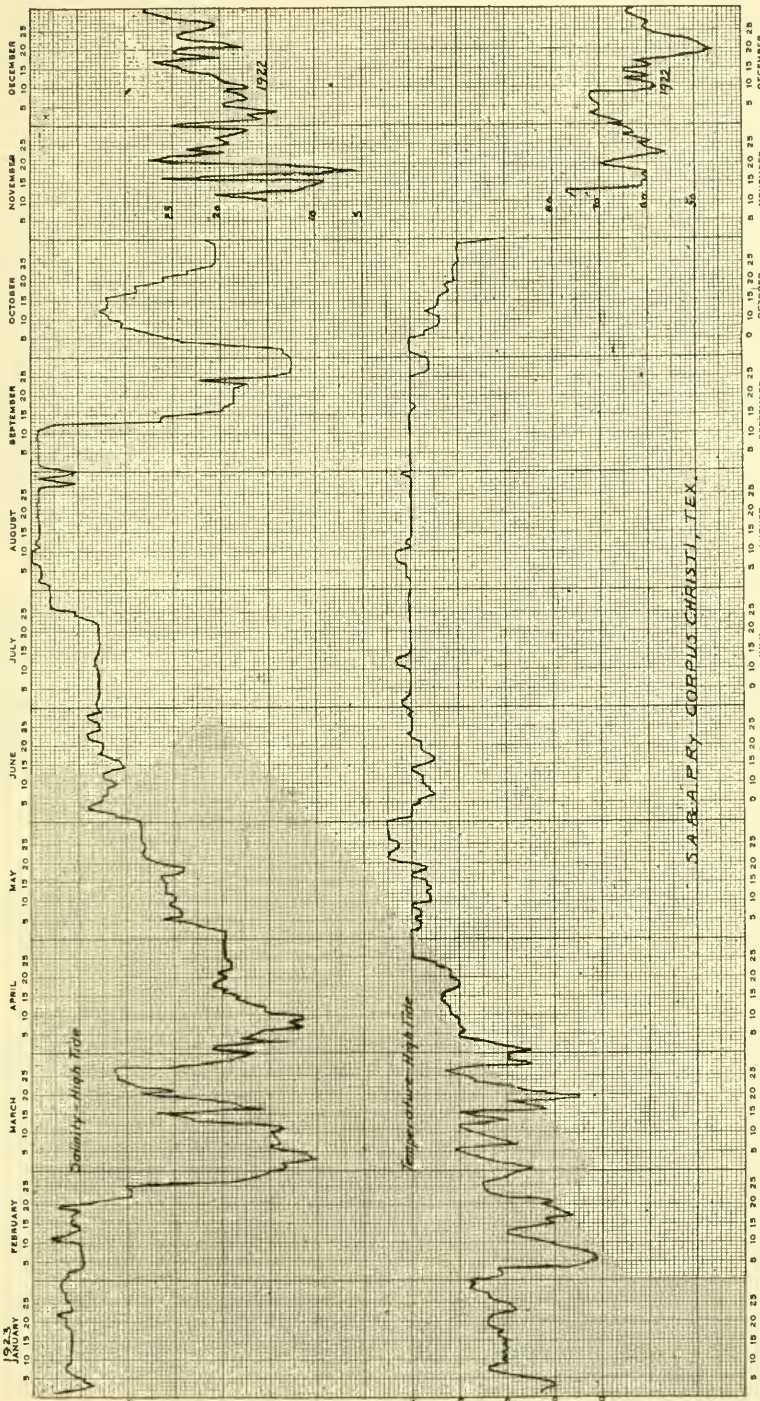


FIG. 131—SALINITY AND TEMPERATURE OBSERVATIONS, S. A. & A. P. RY. CO.'S PIER, CORPUS CHRISTI, TEX.

were recorded by the Gulf, Colorado & Santa Fe Railway at Port Bolivar, and by the San Antonio & Aransas Pass Railroad at Port Aransas and Corpus Christi. These records are shown graphically on Figs. 128, 129, 130 and 131.

Field Tests—Tests of the protective qualities of copper bands and wire were undertaken by the Gulf, Colorado & Santa Fe Railroad. Fifty-four blocks bound with this material spaced at intervals ranging from ½ inch to 2½ inches were placed in the water at Port Bolivar, November 22, 1922. Four of these blocks were removed for examination February 22, 1923. Due allowance being made for seasonal cessation of activity, the inspection showed no material retardation which could be definitely traced to the effect of the metal. The remaining blocks were lost and were not replaced.

Comparative tests of the resistant qualities of different kinds of woods are being carried on by the same company. Samples of longleaf yellow pine, douglas fir, loblolly pine, white oak, toledo wood and manbarklak were submerged at Port Bolivar, November 11, 1922, each sample being enclosed in a galvanized wire basket and all secured in a large container made of galvanized wire. One of the specimens of pine was lost. The other, together with the white oak and douglas fir samples, were removed from the water February 15 and inspected. Summarizing the results of this inspection, Mr. Clapp states as follows:

> 1. The attack by *Bankia gouldi* was not severe during the three months these test pieces were submerged. The pine would have been completely riddled in that length of time if placed in July, judging by the regular test blocks.
>
> 2. The original object of the test was to throw some light on whether marked differences in the shell could be seen in specimens boring into different types of wood. The specimens from these different woods cannot be distinguished from one another, as not the slightest difference has been found.
>
> 3. The difference in attack on the different portions of the block is as marked in these test pieces as in the blocks.
>
> 4. The severe attack on the oak, the fact that the tubes are longer, and a larger percentage of the animals survive the young stage, overshadows the original object of the test. It is remarkable and unexpected.

The toledo wood and manbarklak showed no attack.

Methods of Protection

Creosote Impregnation—Creosote Impregnation is the method in general use for the protection of timber from marine borers in this territory. The record of piles treated to refusal (22 to 24 pounds per cubic foot) with creosote is in general a good one, although such piles are more or less subject to *Limnoria* attack. There are, however, examples of short life which are far from reassuring, and which perhaps can only be explained by imperfect treatment or by important variations in the chemical composition of the oil used, or damage to the timber after treating. A sufficient number of service records have not been obtained to justify definite conclusions.

Armor—Protection with cast iron pipe is a method employed by the Lighthouse Service generally throughout the Gulf district. The structures in the western portion are of recent construction, but it will be noted from the list given below that marked deterioration has already occurred in the case of one of them.

Location and Structure	Date Built	Condition 1922
Timbalier Lighthouse, La.	1917	Good.
Port O'Connor (2 lights) Matagorda Bay, Texas.	1916	Good.
Sabine Pass, Louisiana and Texas—6 Lights	1916	Structure at entrance shows scale having the appearance of carbon, ¼ inch thick, the underlying metal being soft and easily dented. Other 5 structures in good condition.

Conclusions

Timber supporting structures in the territory covered by this report, except at the Port Arthur Turning Basin and in the upper 10 miles of the Houston Ship Canal, must be protected from borers if more than one season's life is desired, and in some locations an unprotected pile cannot be depended on for more than a few months during the season of activity. Based on 1922-23 investigations it seems that timber placed in the water after December 1 is not likely to be seriously weakened before June 1.

From the small number of service records available, conclusions as to the efficacy of various methods of protection used in this particular district can not be safely drawn.

WEST COAST OF MEXICO

Through the courtesy of the Southern Pacific Company and the Kansas City, Mexico & Orient Railway, the Committee has been afforded the opportunity of studying the activity of marine borers in the tidewater terminals of these companies. Testboards were installed at Guaymas (Fig. 132) and Mazatlan (Fig. 133) by the Southern Pacific Company, and at Topolobampo by the Kansas City, Mexico & Orient Railway, as shown in the following table.

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Guaymas—Ardilla Wharf	SP-2	Southern Pacific Co.	Oct. 10, 1922	10.0	8.0
Topolobampo	KMO-1	K. C. M. & O. Ry.	Feb. 1, 1923	......	......
Mazatlan—Urias Wharf	SP-3	Southern Pacific Co.	Aug. 20, 1922	0	6.2

The results of the inspections are as follows:

SP-2—No borers other than a few specimens of *Limnoria* were found though the associated organisms were *Balanus*, Bryozoa (branching and encrusting) and Anomia.

KMO-1—The first specimen of *Bankia mexicana* appeared on the 3rd block, removed March 16, but no considerable growth occurred until after May 1; by the end of July animals 10 inches long were found. The blocks were completely filled by August 15. *Limnoria* was present but not in great numbers. Associated organisms were *Balanus*, Bryozoa (encrusting and branching) Anomia and sponges.

SP-3—*Limnoria* appeared on the first block and larvæ of *Bankia mexicana* on the second, removed September 16. The growth of this species was very rapid reaching a length of about 6 inches in the next month and by the next April the blocks were so thoroughly filled that they were crumbling.

A new board of the 1923 model replaced the former one on May 1, 1923. The attack by *Bankia* on this board commenced in June and became heavier in the following months. The damage done by *Limnoria* was relatively unimportant. The last blocks inspected were removed December 1, 1923, and showed continued activity. Associated organisms were *Balanus* and Bryozoa (*Lepralia* and *Bugula*).

SAN DIEGO BAY

Description

The entrance to San Diego Bay (Fig. 134) is about 10 miles north of the Mexican border. The Bay is the best natural harbor south of San Francisco

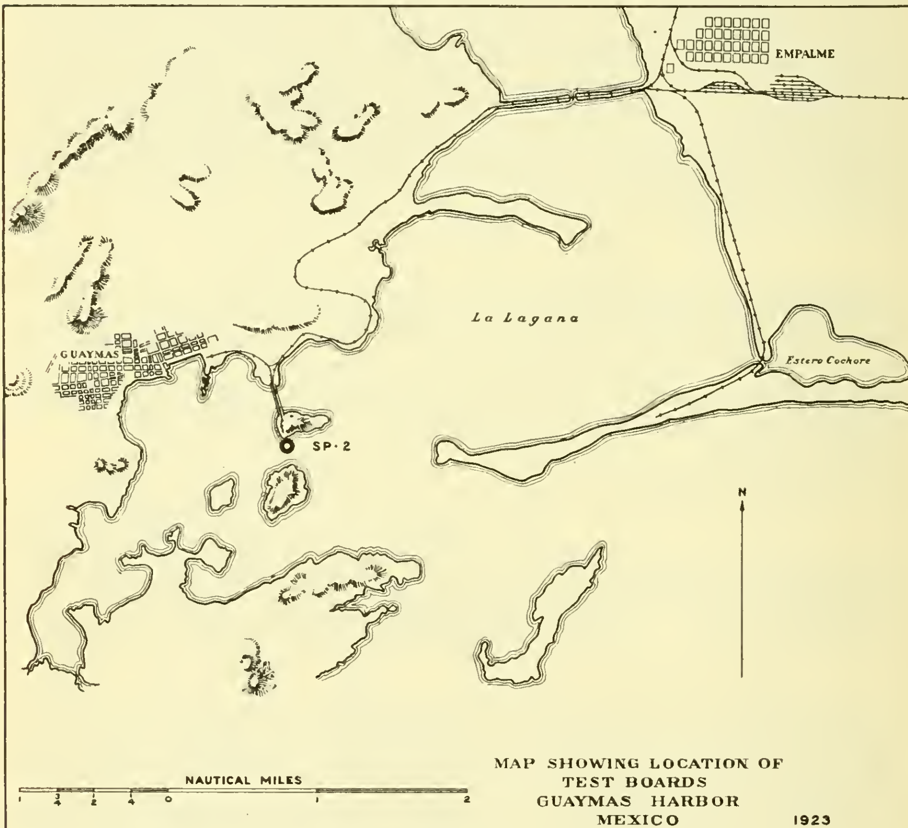


FIG. 132

and affords perfect protection in any weather. It is separated from the ocean by a sand spit, narrow at the south and wider at the north end.

The Bay is about 14 miles long, varying in width from ¼ mile at the entrance to a maximum of 1½ miles and having an area of about 16 square miles. The channel depth at the entrance is 35 feet and the depth at the wharves from 18 to 33 feet, with some points in the Bay between 50 and 60 feet deep.

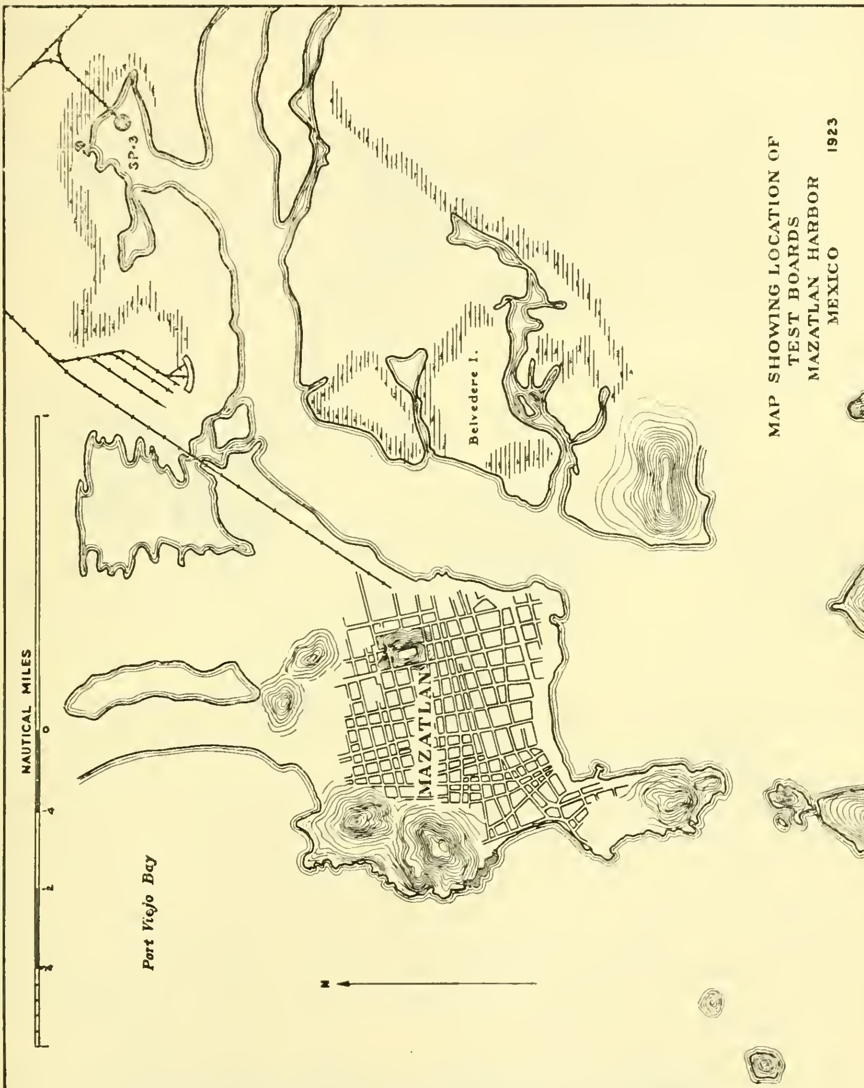

MAP SHOWING LOCATION OF
TEST BOARDS
MAZATLAN HARBOR
MEXICO
1923
NAUTICAL MILES
Port Viejo Bay
MAZATLAN
Belvedere I.
SP.3

FIG. 133

The winds are principally from the northwest and west and seldom exceed 25 miles per hour.

The tidal currents vary from 1 to 2.5 knots per hour.

The salinity varies from a minimum of 31.9 to a maximum of 33.9 parts per 1000 with a mean of 33.6 parts per 1000. The maximum range of tide is 9.9 feet with an average of 5.6 feet, while the temperature range is from a minimum of 56° Fahr. to a maximum of 75° Fahr., with an average of 63° Fahr.

Marine Borers

Past History—It is the opinion of several of the wharf owners that until about 1912 *Limnoria* was the only boring organism in this harbor. This borer was so active that an untreated pile would last only about two years. For the last ten years molluscan borers as well as *Limnoria* have been active and the combination of these two destructive animals has somewhat shortened the life to be expected from untreated timber.

Committee Investigations—Standard test boards were placed as shown below:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Mooring Dolphin No. 2	YD-1101	Navy	Jan. 15, 1923	1.0	18.0
Mooring Dolphin No. 16	YD-1102	Navy	Jan. 15, 1923	1.0	15.5
Mooring Dolphin No. 46	YD-1103	Navy	Jan. 15, 1923	1.0	17.5
U. S. N. Fuel Depot	YD-1104	Navy	Feb. 1, 1923	1.0	16.5
Municipal Pier	YD-1105	Navy	Feb. 1, 1923	1.0	14.5
Naval Air Station	YD-1106	Navy	June 1, 1923	1.0	19.0
Naval Air Station	YD-1107	Navy	June 1, 1923	20.0	0.0
Dolphin No. 46	YD-1108	Navy	June 1, 1923	14.0	2.5
Ft. Rosecrans	A-109	Army	Dec. 1, 1922	1.0	13.8
East Santa Fe Wharf	A-110	Army	Dec. 1, 1922	1.2	22.2

YD-1101—*Limnoria* appeared on the first block and a minute shipworm puncture on block 3, removed March 2. The number of shipworm punctures increased slightly, but no appreciable growth occurred until about May 1. Block 7, removed May 1, contained 16 specimens of *Teredo diegensis*, the longest about 1 inch. Block 9, removed June 1, showed about 15 embryonic shipworms per square inch and 18 animals, some of them 2½ inches long. While the growth of the animals was rather slow, the longest on January 1, 1924, being over 4 inches, the number increased rapidly and by October the blocks were thoroughly honeycombed. The *Limnoria* attack was very heavy. The associated organisms were *Balanus*, Bryozoa (*Lepralia* and *Bugula*), Anomia and a few specimens of *Pecten*, sponges and *Amphipoda*. The last block reported was removed January 16, 1924, and at this time specimens of *Teredo diegensis* contained larvae.

YD-1102—The first shipworm punctures in the blocks were found in block 3, removed March 19. The date of important attack and the beginning of growth appeared to be about one month earlier than at YD-1101. The largest specimen of *Teredo diegensis* found was nearly 5 inches in length. The *Limnoria* attack was quite heavy. One specimen of *Bankia setacea* was found in the block removed December 15.

YD-1103—The first specimen of *Limnoria* did not appear until block 7, removed May 2, and the first of *Teredo diegensis*, in block 8, removed May

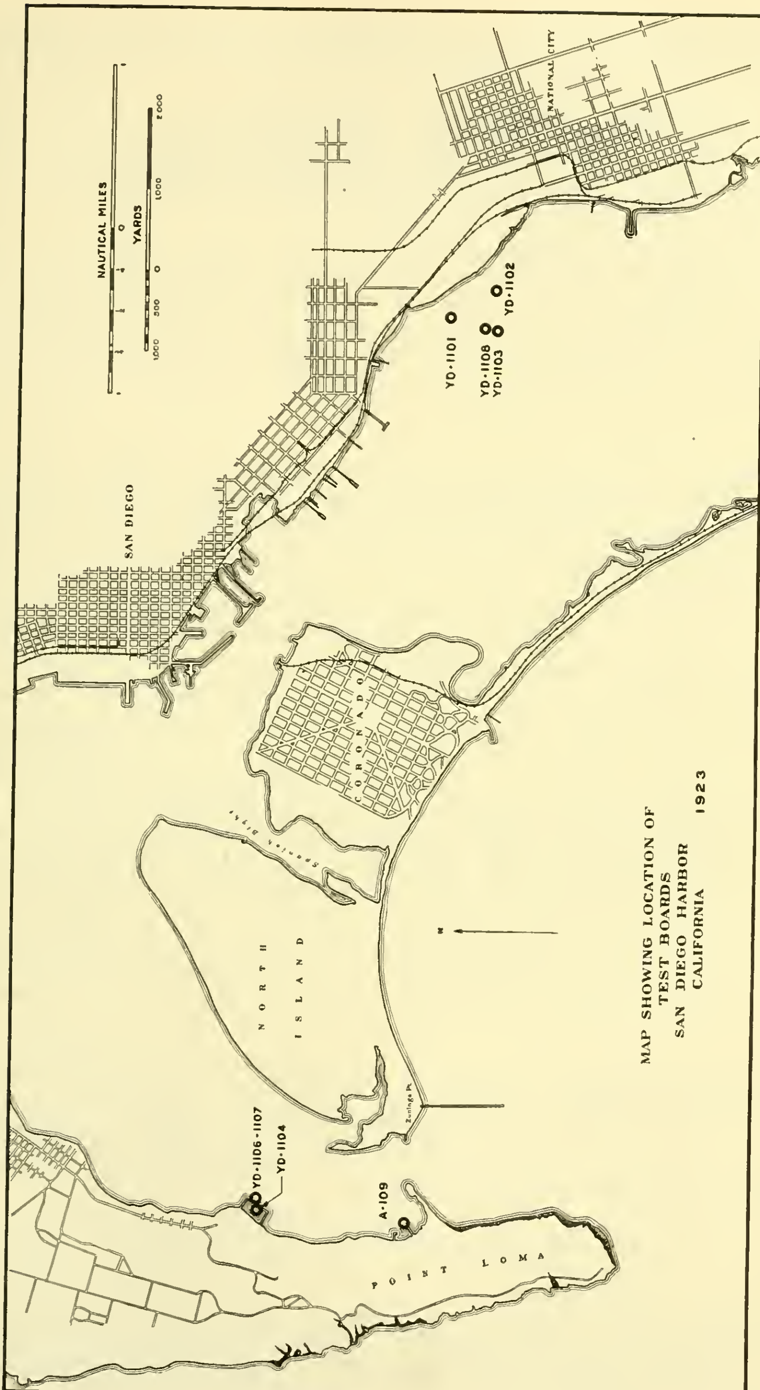

NAUTICAL MILES
YARDS
1000 500 0 1000 2000
SAN DIEGO
NATIONAL CITY
YD·1101
YD·1102
YD·1108
YD·1103
CORONADO
Spanish Bight
NORTH ISLAND
Zuniga Pt.
YD·1106·1107
YD·1104
A·109
POINT LOMA
N
MAP SHOWING LOCATION OF
TEST BOARDS
SAN DIEGO HARBOR
CALIFORNIA
1923

FIG. 134

15. The violence of the attack by both *Teredo* and *Limnoria* increased rapidly and on October 1 was fully as heavy as at YD-1101 and 1102. One specimen of *Bankia setacea* 4 inches long was found in block 16, removed September 17, and the *Teredo* in block 11, removed July 2, contained many larvae. Associated organisms were Bryozoa (*Lepralia*), Anomia, many Amphipoda and polycheate worms. The last block reported was removed January 16, 1924. This block was thoroughly honeycombed by *Teredo* and its surface was destroyed by *Limnoria* action.

YD-1104—The first shipworm puncture was found on block 5, removed April 17, and the first specimen of *Limnoria* two weeks later, but the real attack did not appear until block 9, removed June 15. The attack of *Limnoria* and *Teredo* on this board was not so heavy as on the three preceding boards. The first specimen of *Bankia setacea* 3½ inches long was found in block 14, removed September 4. Associated organisms were Algae, Pecten, Amphipoda and Bryozoa of a number of species. The last block reported was removed January 3, 1924.

YD-1105—The first specimen of *Limnoria* appeared on block 1, removed February 20, and the first shipworm punctures on block 2, removed March 1, but no appreciable growth took place until in block 8, removed June 1. Block 9, two weeks later, showed a very heavy attack by *Limnoria* and *Teredo diegensis*, many of the *Teredo* specimens being 1½ inches long and containing larvae. The number of specimens of *Teredo* found in the later blocks was much smaller than on the boards previously listed, but the *Limnoria* attack was heavier. Associated organisms were fewer than on the preceding boards. The last block reported was removed January 16, 1924.

YD-1106 and 1107—These two boards were placed at the depths shown above. A few specimens of *Limnoria* and about 30 of *Teredo diegensis* larvae appeared on the second block from YD-1106 and a slightly smaller number of both on the corresponding block of YD-1107. There was little variation in the attack on the two boards up to September 15, but the associated organisms were more plentiful on YD-1106. Blocks removed on November 1 showed a few specimens of *Limnoria* and 15 of *Teredo,* the longest 75 mm. in 1106, and only a few punctures in 1107, which was covered with oil scum. All later blocks from YD-1107 were covered with oil, while 1106 showed *Limnoria* and 50 or more burrows of *Teredo diegensis* up to 90 mm. in length. The last block inspected was removed January 18, 1924.

YD-1108—This board was placed above YD-1103. *Limnoria* attack was light until September 4, when the first specimen of *Teredo* appeared, and by the time of the removal of the block on January 16, 1924, the *Limnoria* attack had become heavy and specimens of *Teredo diegensis* had become quite numerous, reaching a length of 120 mm. Some of them were carrying larvae.

A-109—The first shipworm punctures appeared in block 3, removed January 15, 1923, and the first *Limnoria* one month later, but the real attack and the first appreciable growth of *Teredo diegensis,* as well as the first appearance of *Bankia setacea* occurred on block 12, removed June 1. The intensity of attack increased through the summer, but was not so heavy as at the other boards, except YD-1105. Very few specimens of *Bankia* were found. Associated organisms were Bryozoa of many species, Anomia,

Amphipoda and Algae. The last block reported, removed January 16, contained *Teredo diegensis* up to 5 inches in length and *Bankia setacea* 8 inches long.

A-110—The first shipworm punctures appeared in block 2, removed January 2, 1923, and the number had increased to 70 in block 7, removed March 16, though the longest *Teredo diegensis* was only 1/16 inch long. This length had increased to 1½ inches one month later, while by May 15 attack was heavy and the length had about doubled. The first *Bankia setacea* appeared in block 16, removed July 30, and by September 15 the blocks were thoroughly honeycombed, principally by *Teredo diegensis*, though the *Limnoria* attack was also very heavy. Associated organisms were *Balanus*, Bryozoa of several species, Anomia and hydroids. The last block reported, removed January 15, 1924, contained many specimens of *Teredo diegensis*, some of them carrying larvae.

Methods of Protection

Creosote Impregnation—Creosoted piles used in structures of sufficient age to give useful information as to average life have most of them been encased in concrete and there is not sufficient information available from which to draw conclusions as to the life of unprotected creosoted piles in this port. The mooring dolphins recently constructed by the Navy were built strictly in accordance with the recommendations of the San Francisco Bay Marine Piling Committee and are not armored.

Armor—Scupper nailing. The Spreckels Company and the Atchison, Topeka and Sante Fe Railroad both used this method with great success. A description of the structures in which it was used will be found in Chapter VI, page 98.

Concrete Jackets—The temporary pier at the Naval Air Station was built of unprotected timber in May, 1918. The *Limnoria* attack was heavy during the first year and the piles were encased in concrete jackets 3 inches thick. When this pier was removed in June, 1921, to make way for a permanent structure, the jackets and piles were all found to be in good condition.

The "Bunker Wharf" of the Spreckels Company was constructed in 1887 on creosoted piles and between the years 1889-1893 these piles were encased in concrete jackets made with 1 to 1 or 1 to 1¼ mortar, depending on the depth of water. The forms were made in halves, placed and bolted by divers. No bearing piles have been replaced in 35 years, though some of the jackets have required repair. It has been found at points where the concrete has broken away from the pile that a sandy, gritty surface remained, which seemed to give at least temporary protection.

The San Diego Municipal Wharf is built on concrete cylinders molded in place over three pile clusters. These supports, built in 1914, appear to be in good condition, but the floor beams and girders at a number of points show discoloration and signs of spalling over the reinforcing rods.

Substitutes for Timber

Concrete—The Army Mine Wharf was constructed in 1910 on concrete bearing piles which were reported to be in good condition in 1922.

The pier at the Naval Air Station was constructed in 1920 on 140 18-inch by 18-inch and 232 14-inch by 14-inch square precast piles. The 18-inch

piles were reinforced with four 1-inch and the 14-inch with four $\frac{7}{8}$-inch deformed square bars hooped with $\frac{3}{8}$-inch diameter bars with $1\frac{1}{2}$ inches cover. The aggregates were hard granites from the bed of the Otay River and medium sand. The cement was Victor Brand, the water fresh from the city supply; the steel was free from rust and the mixture was $1:1\frac{1}{2}:3$, of a slightly quaking consistency. Part of these piles were jetted and part driven with a No. 1 Vulcan hammer. A concrete sheet pile sea wall was built at the same time and with the same methods and materials. This structure, at the age of two years, showed no deterioration.

The Naval Fuel Depot is built on concrete filled steel cylinders made of $\frac{1}{2}$-inch steel plate supported by pile clusters cut off at low water. The deck and superstructure are steel. The plates in the cylinders show very little corrosion and the superstructure is in good condition though it has not been repainted since its construction in 1909.

There is a considerable amount of floating oil around this structure which has preserved the steel below high water and in the opinion of the Public Works Officer the thick accumulation of coal dust above the water level has acted as a protective coating preventing rust.

Cast Iron—The Quarantine Station Wharf is built on cast iron columns supported on unprotected wooden piles cut off at the mud line. It was built in 1888 or 1889 and its history is reported by the U. S. Engineer Office as follows:

> "Captain Watkins, who has been at the station since 1900, reports that the cast iron piling is brittle and that a number of them have broken under the impact of a vessel striking the wharf. (We viewed one that had been broken short off by the stem of a small motor dory.) Another objection is that in some cases the current has scoured the sand below the bottom of the bell, leaving the stub wooden pile open to attack of borers. Several piles have been found suspended from the dock due to this. A third objection is lack of rigidity due to difficulty of getting a snug fit of the bell over the supporting wooden pile. (Diagonal rod interbracing originally installed to stiffen the structure was removed because of the kelp it collected.) Repair of broken piling has been fairly simple by inserting a pipe, putting a clamp over the break and filling with concrete. Captain Watkins is of the opinion that the piling should be filled with concrete when built, strengthening against the apparent crystallization and securing a snugger fit upon the supporting pile.
>
> "To offset the objections is the long life, as the piles show surprisingly little corrosion. Contractors are at work now putting on an entire new superstructure of timbers and decking on the long approach to the main wharf, supported by the original hollow cast iron piling."

Conclusions

It appears that so far as indicated by test blocks the attack by *Bankia setacea* is negligible; that *Limnoria* attack is heavy throughout the harbor though perhaps a little heavier toward the southern end than farther north; that while larvae of *Teredo diegensis* are deposited throughout a greater part of the year serious attack does not occur before the month of April. The close of the season of activity has not yet been determined.

The results obtained with concrete jackets on creosoted piles with the exceptional character of maintenance these structures have received, have been very satisfactory.

The nail armor has been very effective and its record should encourage the use of this method where labor costs are not prohibitive or with machine methods of driving the nails which may be developed.

The long life of the cast iron wharf at the Quarantine Station, in spite of the evident defects in design is very significant.

LOS ANGELES HARBOR

Description

A portion of San Pedro Bay (Fig. 135), which was naturally protected from northerly and westerly winds, has been converted into a safe harbor at all times by the construction of a breakwater about 2.11 miles in length and by a large amount of dredging. The outer harbor has a general depth of 35 feet and the channels, which are from 200 to 500 feet wide, have a depth of 30 feet, except for a portion of the channel in the Inner Harbor, which has been dredged to 20 feet.

Tidal currents exist in the channels of sufficient strength to facilitate the distribution of borers.

Marine Borers

Past History—The present harbor is comparatively new, but the structures in San Pedro Bay and vicinity have shown the presence of *Limnoria* and the molluscan borers as far back as there are records. Both types of borers are very destructive, *Limnoria* being perhaps the worse of the two.

Committee Investigations—Standard test boards have been maintained as shown below:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Municipal Pier, Long Beach.....	A-106....	Army..............	Oct. 31, 1922	1.75	6.0
Berth 40, L. A.................	A-107....	Army..............	Nov. 13, 1922	1.66	18.0
Berth 152......................	A-108....	Army..............	Nov. 15, 1922	1.8	25.0

A-106—The first shipworm punctures appeared on block 1, removed November 15, and the first *Limnoria* on block 3, removed December 16; in block 7, removed February 16, the specimens of *Teredo diegensis* had reached a maximum length of 3/8 inch. Block 9, removed March 16, contained a few specimens of *Teredo diegensis* up to 1 inch in length, containing larvæ, but this length and the number of animals found did not appreciably increase until about May 1, when a more rapid growth commenced. The number of specimens of *Teredo* found in any block never exceeded about 70 and the length was not more than about 4½ inches. The *Limnoria* attack was very heavy. Associated organisms were *Balanus,* Bryozoa, Pecten, Crepidula and *Ostrea.*

A-107—No life appeared on these blocks until block 3, removed January 16, 1923, when a few shipworm punctures were found. A few specimens of *Limnoria* appeared on later blocks but there was no increase in the number or size of those of *Teredo diegensis* until April 2, when one of them had reached a length of 3/8 inch and when a more rapid growth started. Block 11, removed May 16, showed one specimen of *Bankia setacea* and the next block, two weeks later, contained a few of *Teredo diegensis* 2 inches long and one of *Bankia setacea* over 6 inches long. The number and size of both species increased rapidly in June and those of *Teredo* continued to increase until there were 50 to 75 per square inch up to 4 inches in length,

with a few specimens of *Bankia* up to 10 inches long. *Limnoria* attack was light. Associated organisms were Bryozoa (*Crisia* and *Microporella*). The last block removed, January 16, 1924, was thoroughly riddled by *Teredo diegensis* and contained a few specimens of *Bankia setacea*.

A-108—The first shipworm punctures appeared in block 3, removed January 2, and the first *Limnoria*, February 17. The shipworms, *Teredo diegensis*, reached a length of 3/8 inch in block 8, removed March 16, and one month later a specimen 4 inches long was found, but the number did not appreciably increase until the last half of May; by September 15 the blocks were thoroughly honeycombed, some of the *Teredo* specimens being about 8 inches long. *Limnoria* attack was negligible. Associated organisms were *Balanus*, Bryozoa (*Crisia*) and Anomia. The last block inspected was removed January 16, 1924.

Some time previous to 1909 piles supporting several structures were encased in concrete jackets as a protection against borers. In 1922 a number of these piles were removed in the course of the construction of the new harbor and the concrete was found to have been attacked by rock borers. There is no exact record as to the date of placing the jackets or the method of construction except that wooden forms left in place were used. The concrete was friable and contained few coarse aggregates and some specimens showed the characteristic pink color caused by the disintegration of the cement. The best specimen tested has a crushing strength of 1,726 pounds per square inch. This concrete was undoubtedly far from being of the best quality and it is still questionable whether these animals could destroy first class concrete, though they will undoubtedly assist the chemical disintegration when that cause of failure becomes active.

Roughly, about 50 per cent of the jackets examined were rather heavily attacked and few of them showed no attack. In one specimen examined there were about 8 borers per square foot and heavier attacks are reported.

The principal boring species was the *Pholadidea penita* (Conrad). Specimens of *Petricola carditoides* (Conrad) were also found, but it is thought that this species did not bore but lived only in previously existing holes.

Methods of Protection

Practically all wooden harbor structures are protected by creosoting or by concrete jackets, but service records available do not cover a sufficiently long period to be of value.

Substitutes for Timber

Reinforced Concrete—The following statement furnished by the Harbor Department of the City of Los Angeles shows the concrete structures in the harbor. It will be noticed that none of them are yet old enough so that deterioration could be expected.

Berths 56-60

- Length of Wharf—2,920 ft.
  - Reinforced Concrete Piles.
  - Materials.
    - Aggregate—Sand and gravel from San Gabriel and Puente Largo, Wash.
    - Cement—Colton, Riverside and Golden Gate.
  - Gaging water—Fresh.
  - Reinforced with spiral hooping and ¾-in. bars running longitudinally—1.3 per cent to 1.7 per cent steel.

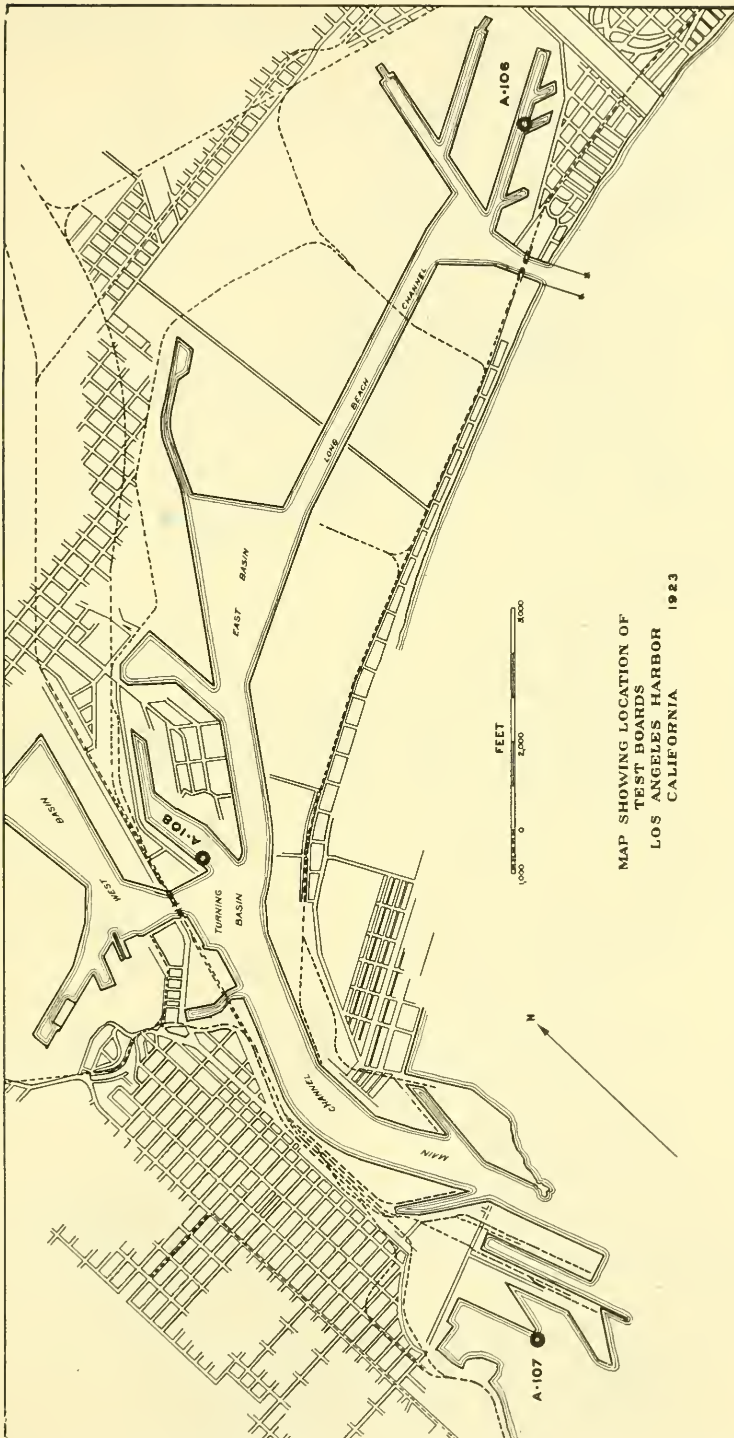

MAP SHOWING LOCATION OF
TEST BOARDS
LOS ANGELES HARBOR
CALIFORNIA
1923
FEET
A·106
A·107
A·108
LONG BEACH CHANNEL
EAST BASIN
WEST BASIN
TURNING BASIN
MAIN CHANNEL
N

FIG. 135

Mix—Originally 1:1½:3 and later changed to 1:1⅓:3½. Cover over reinforcing—2 in. Piles painted with one coat of "Ironite." Precast.

Built in 1913.

Condition satisfactory—could find no deterioration.

Date last inspected—June, 1923.

BERTHS 187-188:

Length of Wharf—1,159 ft.

Reinforced Concrete Piles.

Materials.

Aggregate—Sand from San Gabriel, Wash.

Cement—Victor.

Gaging water—Fresh.

20-in. pile with 12-in. hollow core.

18-in. pile with 10-in. hollow core.

Spiral reinforcement and 8 ⅝-in. longitudinal bars—1.2 per cent to 1.4 per cent steel.

Mix—About 1:2½.

Cover over reinforcing, 2½ in.

Built in 1920, made of Gunite 4 in. thick blown around a paper core, 12 in. diam.

No deterioration as yet can be noted.

BERTHS 189-191:

Length of wharf—1,176 ft.

Reinforced concrete piles.

Materials:

Aggregate—Sand and gravel from San Gabriel River bed.

Cement—Victor.

Gaging water—Fresh.

18-in. square piles—corners. chamfered 3 in.

Steel wires for hooping and ten 1-in. down to eight ¾-in. bars, depending on length of pile for horizontal reinforcement—1.1 per cent to 2.5 per cent reinforcement.

Mix—1:1.8:3.

Cover over reinforcement, 3 in.

Built and driven in 1922.

BERTH 232:

Length of wharf—1,120 ft.

Reinforced concrete piles.

Materials:

Aggregate—Sand from San Gabriel River bed.

Cement—Victor.

Gaging water—Fresh.

17 in. round piles, from eight ⅝-in. diam. to six ⅝-in. diam. longitudinal rods, depending on length of pile—0.8 per cent to 1.1 per cent reinforcement.

Mix—1:2:6.

Cover over reinforcement, 2½ in.

Made of Gunite.

Built and driven in 1922.

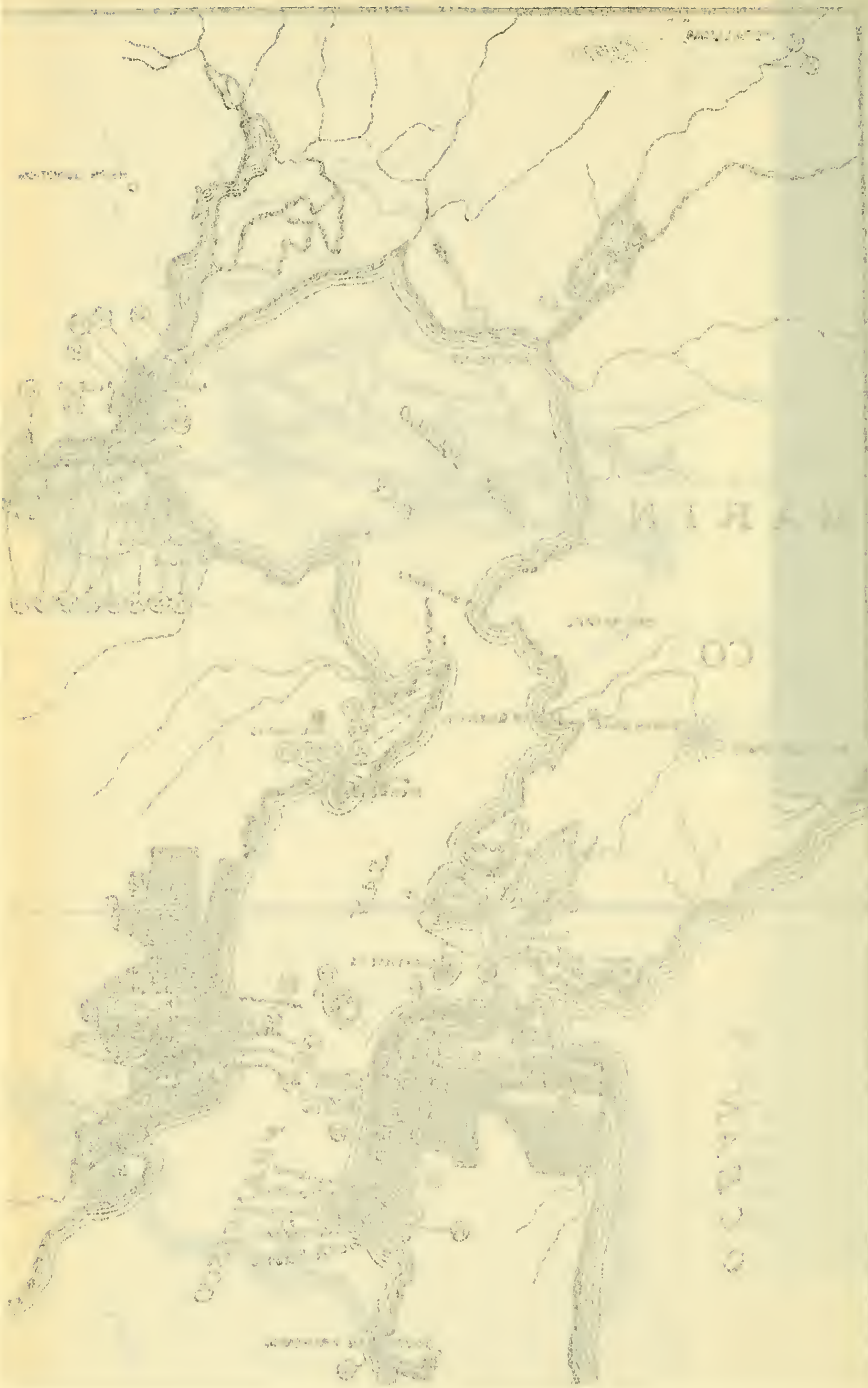
It was found that the hollow piles used in Berths 187-188 were more expensive than solid piles and therefore this method was abandoned and the piles made solid. The cost of the gunite pile is said to have been approximately $2.75 per linear foot as compared to about $3.25 for poured piles.

Aside from the wharf structures, we have a reinforced gunite landing barge, 20 ft. by 100 ft. by 6 ft. deep.

Materials:

Aggregate—San Gabriel River sand.


SAN FRANCISCO BAY
AND
TRIBUTARIES
Scale
0 2 4 6 8 10 MILES
Drawn For
San Francisco Bay Marine Piling Survey
December 1920
N
PETALUMA
NAPA JUNCTION
BLACK POINT
MARIN
CO.
SAN PABLO
BAY
SAN RAFAEL
GREEN BRAE
SAN QUENTIN
MT TAMALPAIS
TIBURON
ANGEL IS
SAUSALITO
FORT BAKER
ALCATRAZ IS.
GOAT IS
FORT MASON
FORT SCOTT
SAN FRANCISCO
China Basin
Central Basin
India Basin
HUNTERS PT
South Basin
SOUTH SAN FRANCISCO
SAN MATEO
OCEAN
PACIFIC
SAN
FRANCISCO
BAY
DUMBARTON
PINOLE
HERCULES
OLEUM
RODEO
CROCKETT
PORT COSTA
VALLEJO JUNC
SELBY
MARE IS
VALLEJO
BENICIA
MARTINEZ
SUISUN
BAY
AVON
BAY PT
MALLARD
PITTSBURG
ANTIOCH
DUTTON
COLLINSVILLE
EMMATON
SHERMAN ISLAND
SAN JOAQUIN R.
SACRAMENTO R.
RIO VISTA
THREE MILE FERRY
N FK MOKELUMNE R.
OLD RIVER
RICHMOND
PT RICHMOND
PT SAN PABLO
PT SAN PEDRO
BERKELEY
OAKLAND
ALAMEDA
MT DIABLO
A. L. BELL



Cement—Bear brand.
Gaging water—Fresh.
¾-in. steel twisted rope, Clinton electric welded fabric and triangular mesh.
Four-in. walls, bottom and deck—about 2½ per cent steel.
Mix—About 1:2½.
Cover over reinforcement, 1½ in.

Built in 1918.

Present condition:

No recent inspection made. Barge has not settled any in the water and from superficial examination, no deterioration was found.

In a wharf now under construction a new method of protection is being used and the service record of this structure will be watched with interest. These piles are 16 inches square and from 30 to 52 feet long, with longitudinal reinforcing ⅝ to ¾ inches with spiral hooping and a small circular hole cast in the center of the pile to aid in impregnation. The mixture principally used was 1:3:3, though a mixture of 1:3½:3½ as well as others are being tried. The concrete is mixed rather dry and carefully tamped in the forms.

After the piles are seasoned they are placed in a tank 8 feet square and 60 feet long, filled with cold asphalt of 40-50 penetration. The temperature is raised to about 450° Fahr. and then allowed to fall to 212° Fahr., at which time the piles are removed. The whole operation requires 24 hours. On account of the uneven expansion of the concrete and steel, cracks are formed, which aid in the impregnation. This cracking has been said by some not to be harmful to the strength of the piles, since the asphalt firmly cements the cracks. Confirmation of this hypothesis awaits further test and observation.

By this method it has been possible to thoroughly impregnate the piles and thus it is thought that the concrete will be protected from disintegration and the reinforcing metal from corrosion. Recent experiments on this type of pile are claimed to have produced full size pile samples free from cracks and fully impregnated with asphalt.

Conclusions

All structures in the harbor are subject to heavy attack from marine borers and piles should therefore be protected in all except very temporary structures.

While *Teredo diegensis* seems to breed slowly through the winter a heavy attack need not be expected before May 1, and since *Bankia setacea* appears later this may be considered the end of the period of shipworm inactivity. *Limnoria* is active, but will not alone destroy a structure in one season.

The concrete structures are too new to furnish information as to probable life, but the varied methods of construction used and the complete records available justify careful study of the service given.

SAN FRANCISCO BAY

The greater part of the information contained in this report on San Francisco Bay is abstracted from the three reports of the San Francisco Bay Marine Piling Committee, published in 1921, 1922 and 1923.

Description of San Francisco Bay and Tributaries

San Francisco Bay (Fig. 136) proper extends from its junction with San

Pablo Bay between Points San Pedro and San Pablo southeastwardly about 40 miles. The entrance to the Bay from the Pacific, the Golden Gate, is about 10 miles south of Point San Pedro. The Bay is about 12 miles wide at its widest point and has an area of about 228 square miles.

The depth in the Golden Gate is about 300 feet and the average current on flood is 3.3 knots and 3.4 knots on ebb with a maximum ebb current observed of 6.5 knots.

The northern extension of San Francisco Bay, San Pablo Bay, is about 10 miles long by 8 miles wide and has an area of about 112 square miles with a channel depth of about 30 feet, and tidal current averaging slightly less than 2 knots on both ebb and flood.

Carquinez Strait enters San Pablo Bay from the east and connects that body of water with Suisun Bay. It is from ½ to 3½ miles wide and 6 miles long, with a depth of from 30 to 60 feet and has tidal currents averaging from over 2 knots on flood to over 3 knots on ebb, with 6 knots or more on ebb tide coincident with floods in the San Joaquin and Sacramento Rivers.

Suisun Bay is a generally shallow body of water, which is really the delta of the San Joaquin and Sacramento Rivers. The channels are narrow and winding and are used only by light draft vessels.

The watershed tributary to San Francisco Bay is about 6,200 square miles, of which 5,800 is in the watersheds of the San Joaquin and Sacramento Rivers, whose waters enter through Suisun Bay, Carquinez Straits and San Pablo Bay.

The general salinity conditions in San Francisco Bay proper do not vary sufficiently from the normal to greatly affect marine life, but in San Pablo Bay the effect of the discharge of the Sacramento and San Joaquin has a distinct influence on salinity (Fig. 137), while in Carquinez Strait the river discharge lowers the salinity to zero at times (Fig. 138).

Temperatures at Tiburon have an annual average of 55.1° Fahr., with a January average of 47.5° Fahr. and a July average of 62.6° Fahr. At Goat Island the corresponding figures are 54.4° Fahr., 48.1° Fahr. and 59.5° Fahr., respectively. In the Mare Island Channel July and August, 1920, averaged about 62° Fahr., with a maximum of 64° Fahr. at the bottom and 67° Fahr. at the surface, and there was no considerable variation from these figures until October. January, 1921, showed a minimum of 39° Fahr. at the bottom and 42° Fahr. at the surface, with an average of about 45° Fahr., while June, 1921, showed its highest surface temperature to be 72° Fahr. and 66° Fahr. at the bottom, with an average of about 65° Fahr., while the variation in Carquinez Straits is from a minimum of about 40° Fahr. to a maximum of 70° Fahr.

Marine Borers

Past History—Structures in San Francisco Bay have been subject to attack by marine borers ever since records have been kept, though tradition says that the shipworm did not become a menace until the great shipping increase caused by the gold rush in 1849. There is a pile section in the Philadelphia Academy of Natural Sciences, collected in San Francisco Bay in 1867, which was heavily attacked by *Bankia setacea*. So far as the biologists know the only borers existing in the Bay prior to 1914 were the *Bankia setacea* and *Limnoria lignorum*. The greatest destruction occurred near the Golden Gate and on parts of the San Francisco waterfront, where an unprotected pile might not last over a few months, while

on the Oakland waterfront eighteen months to three years' life might be expected. In San Pablo Bay, Carquinez Straits, Suisun Bay and the Sacramento River, unprotected structures had been standing 30 or 40 years without attack until 1917, but since that time every waterfront structure of untreated timber between San Pablo Bay and Antioch on the Sacramento River has been attacked by *Teredo navalis* and most of the structures as far as Suisun Bay have been destroyed.

The attack of the *Teredo navalis* has also extended to the south end of the Bay, but the damage has been less than in the north, because there are fewer structures to serve as breeding grounds. The attack on the creosoted piles of the Dumbarton bridge has been fairly destructive, but was due principally to *Limnoria* following abrasion of the creosoted timber.

Teredo navalis is the most widely distributed species in the Bay, and consequently the most destructive, while *Bankia setacea* is less widely distributed, but just as destructive where it exists. *Teredo diegensis* is of less economic importance, as it has been identified in only one locality.

The two crustacean borers found in San Francisco are the *Limnoria lignorum* and a species of *Sphaeroma*. The former is found in all parts of San Francisco Bay proper and is especially destructive on the San Francisco and Oakland waterfronts, while *Sphaeroma* is found, not only in San Francisco Bay itself, but also in its tributaries as far as Antioch on the Sacramento River. *Sphaeroma* has so far shown itself of little economic importance.

Committee Investigations—The San Francisco Bay Marine Piling Committee has placed and maintained a large number of test boards and in addition to determining salinities and temperatures has made a number of laboratory experiments to find previously unknown facts regarding the life history, habits and requirements of *Teredo navalis*, the most important species of borer with which they had to contend. The details of this work will be found in the reports of the Committee.

The purely scientific studies of the Committee have produced the following results:

Evidence drawn from studies of a large number of shells and pallets shows that the range of individual and environmental variations in *Teredo navalis* is so great that all forms of *Teredo* of economic importance in San Francisco Bay, exclusive of *Teredo diegensis*, may properly be included in this species.

Evidence that *Teredo navalis* maintains its normal activity in salinities as low as 9 parts per 1,000; that below 7 parts per 1,000 the proportion of active individuals decreases until at a salinity of 3 parts per 1,000 none are active; that the average lethal salinity for this species is 5 parts per 1,000; that 90 per cent of the individuals will be killed by a salinity below 4 parts per 1,000 extending over a period of 33 days, but that if a rise in salinity occurs even for a relatively short period, the animal can renew its supply of salt water and continue to live; that with 33 days of salinity below 4 parts per 1,000, 10 per cent of the animals are still alive and may continue to spread the attack if the salinity increases to a sufficient amount before their death.

Evidence that during its passage through the digestive tract of *Teredo* about 80 per cent of the cellulose and from 15 per cent to 56 per cent of the hemicellulose is removed from the wood; that the carbohydrates which disappear are probably used as food by the *Teredo;* that the digestion

of wood produces optimum conditions for the absorption of toxic substances contained in it and that therefore impregnation with a toxic substance having the other necessary qualities will provide efficient protection for the timber.

Methods of Protection

The reports of the San Francisco Committee contain tabulations of the service records of wooden piles with various methods of protection, of creosoted structures and structures built on substitutes for timber. Over 250 structures are listed. The Committee draws the following conclusions from a study of the records so far as they relate to timber construction:

> "1. Marine borers are very active in San Francisco Bay and connected waters, and in places where their attack is severe will destroy untreated piling in as short a time as six to eight months. In other places the untreated piling may last from two to four years.
>
> "2. The information secured indicates that it is reasonable to expect a life of five to eight years from paint and batten protections in sheltered waters, if the work is well done. If it is not well done, or if the covering is damaged by careless handling, or if unprotected wood is exposed by mud scour, this range of life cannot be expected.
>
> "3. The data in hand indicates that it is fair to expect creosoted douglas fir piling in San Francisco Bay to give a life of 15 to 20 years under present conditions *and practice.* Certain piles are of authentic record from the Oakland Long Wharf, which were sound when removed after a service of 29 years. Poor treatment, or damage to creosoted piling by careless handling, rafting, storage or construction, will materially reduce the life which might otherwise be rendered by such piling.
>
> "4. Most of the attack on creosoted piling by marine borers, which the Committee has observed throughout this survey, appears to have begun in spots where untreated wood has been exposed by damage in handling the piles or placing the superstructure. It is urgently recommended that improvements be made in the methods of handling creosoted piles and building structures upon them, so that damage to the surface of the piles may be reduced to a minimum. *Gratifying improvement has taken place during the current year.*
>
> "5. Precast reinforced concrete piles and pile casings have not been in use in San Francisco Bay a sufficient length of time to determine their ultimate life. A detailed examination of structures which have been in service for *more than* ten years shows no evidence of deterioration below high water line, and they seem capable of a long further life. The length of life to be expected from this type of construction is largely dependent upon the quality of materials and workmanship and the skill and care with which they are employed, and any laxity in these particulars will materially shorten the length of service which may be secured.
>
> "6. Reinforced concrete cylinders cast in open caissons have been in use *since* 1910. Although the average life of many earlier cylinders has been considerably shortened by construction defects, these cylinders with minor repairs still give promise of a long period of service. Similar cylinders designed and constructed in accordance with best modern concrete practice should constitute a type of construction only excelled for longevity by solid fill or mass concrete.
>
> "7. Cast in place concrete pile jackets may be expected to give satisfactory results if properly constructed of suitable materials and if proper regard is given toward exclusion of sea water from forms. The difficulties of this type of construction, however. are of such nature that the probability of securing a maximum length of life is less than in the case of precast concrete piles or pile casings.
>
> "8. Copper sheathed piles have given very satisfactory service in locations where damage from abrasion and theft can be minimized. Such piles carefully prepared and handled fall into the class of best surface protections,

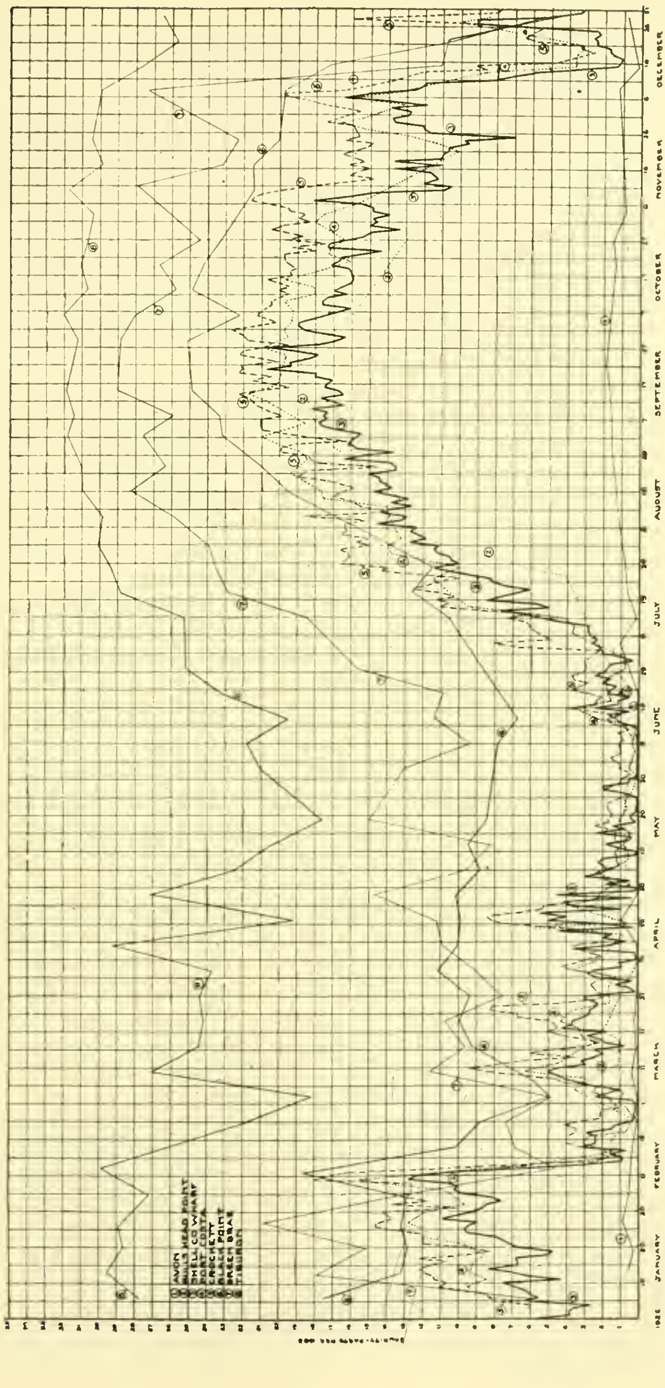


FIG. 137—SALINITY OF WATER AT VARIOUS LOCATIONS, SAN FRANCISCO BAY, CAL.

when used under the conditions indicated, *but are easily damaged by either abrasion or theft.*

"9. The selection of a type of piling or pile protection for a given structure must be made upon the basis of cost and permanence of the materials under consideration, the character of the structure and the probable need for future alterations to meet the changing requirements of commerce. When a comparatively short increase over the life of untreated wooden piling is sufficient, the surface protections will often be found economical in waters not exposed to severe storm action; if a moderately long physical life approximating the average economic life of marine structures in this harbor is desired, a good creosote treatment will provide it at the lowest annual cost, so far as present knowledge goes; if conditions warrant building for the greatest permanence, with less regard for first cost, concrete construction has shown a high value in this harbor. For the protection from further damage of wooden piles already in place and showing attack by borers, not yet severe enough to require condemnation, the concrete casing, precast or poured in place, is the only means of salvage so far found by the Committee."

Substitutes for Timber

Wrought Iron and Steel—There are five piers reported on cast iron piles and two on wrought iron, containing 505 cast iron and 179 wrought iron piles, both cylindrical and both filled with concrete. The cast iron piles were placed between 1870 and 1903 and the wrought iron in 1886 and 1897. Sixty-five piles out of 145 have been replaced on account of breakage in the pier on Alcatraz Island since 1870 and the bracing has been renewed five times. In the other cast iron pile piers only five replacements have been made and no wrought iron piles have requird renewal.

A pier on cast iron cylinders 4 feet in diameter and 2 inches thick filled with concrete was built at the Tiburon coaling plant of the Navy in 1906-08 and is reported to be in excellent condition with no maintenance expenditures except painting above water level.

Concrete—Two types of concrete construction are in general use. In one the deck of the pier is carried on cylinders sunk to a satisfactory foundation. They are from 5 to 7 feet in diameter and were constructed inside of steel caissons which were unwatered before pouring the concrete. The reinforcement consists of ⅞-inch square bars spirally hooped with No. 0 wire. The concrete mixture was one part cement to six parts aggregate and the reinforcing had a 3-inch cover.

There are 12 piers, containing 5,198 cylinders, built between 1909 and 1916, and 457 of the cylinders had required repair up to December, 1922, but none of them had failed.

The other type of concrete construction makes use of reinforced concrete piles which are generally from 16 to 20 inches square, made with a 1:5 mixture and reinforced by from four ¾-inch bars to six 1-inch bars, depending on the length of the piles. No. 3 wire is used for spiral hooping and there is 2-inch cover over the reinforcing.

There have been 19 structures containing 8,637 piles built between 1911 and 1922 and none of the piles have as yet required replacement, but many of those over 10 years old and some of less age show rust streaks or cracks over the reinforcing above high water. For example, three structures reported in the second report (1922) have the following record: In one built in 1911, 30 per cent show rust streaks or cracks, in another built in 1912, 25 per cent, and in one built in 1915, 10 per cent.

There is a large amount of sea wall on the San Francisco waterfront generally built of concrete blocks cast and seasoned in air. It is thought to be in good condition.

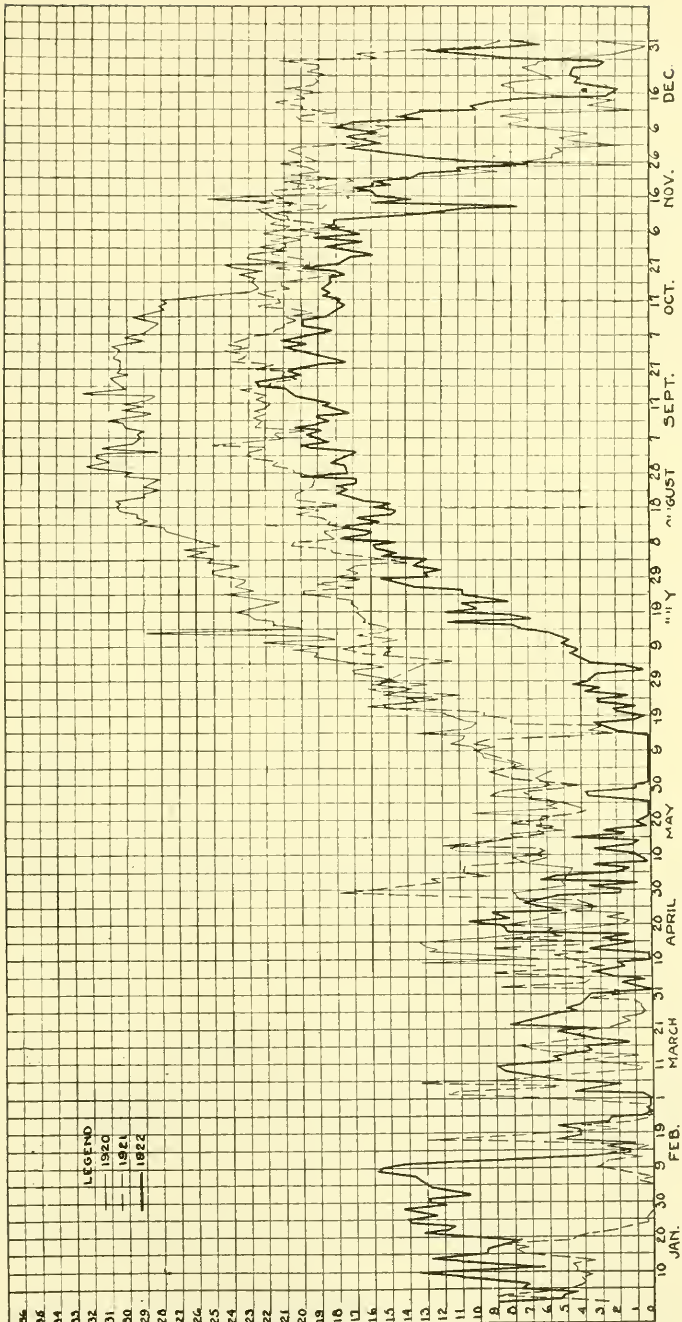


FIG. 138—COMPARATIVE SALINITIES, 1920-1921-1922, AT MARTINEZ, CAL.

At the Mare Island Navy Yard there is a concrete quay wall cast in place and built at various times since 1892. The salinity at this point is generally low and there has been little if any visible deterioration.

The cement used had an average composition of

Silica	21.6%
Ferric oxide	3.8
Alumina	7.9
Calcium oxide	61.6
Magnesium oxide	1.2
Sulphur trioxide	1.2
Loss on ignition (moist alkalies)	2.7

Specimens were cut from the walls constructed at various dates, the large stones of the aggregate removed and the remainder of the specimen analyzed, with the results as shown below, which are quoted from a report by the Public Works Officer of the Yard:

Date Concrete Placed	Wall No.	Present per cent Silica	Present per cent Calcium Oxide	Present per cent Magnesium Oxide	Present per cent Sulphur Trioxide	Present per cent Salt
1892	N	64.4	12.6	2.4	.80	1.30
1893	G	76.9	8.4	2.0	.62	.17
1897	D	74.0	5.5	3.0	.80	.12
1898	B	59.9	8.9	7.2	.88	.91
1898	L	67.8	11.6	1.9	.76	.58
1898	C	57.6	18.4	2.1	.70	.16
1899	O	73.4	4.3	6.3	.35	.58
1899	E	65.1	12.3	2.8	.74	.62
1899	M	62.8	1.3	2.4	.00	.00
1899	K	61.8	20.6	1.1	1.20	1.50
1902	F	78.1	7.8	2.1	.39	.54
1903	H	72.9	8.8	2.7	1.20	.41
1909	I	67.8	13.8	1.9	1.30	.74
1912	Q	66.0	11.0	2.28	.61	1.73
1915	P-1	55.3	19.9	1.5	.38	1.20
1915	P-2	49.3	18.5	2.28	1.60	1.80

"These results are irregular, but, when averaged by years, show a gradual leaching out of lime in approximate proportion to the age of the sample.

Date placed	1893	1897	1898	1899	1902	1903	1909	1912	1915
Present per cent of lime	8.4	5.5	12.9	9.6	7.8	8.8	13.8	11.0	19.2

"This lime content is essential to the lime-silica combination, which is the strength of the cement."

A further quotation from this report is as follows:

"No other methods of safeguarding concrete from salt water and abrasion have been used at this yard than the use of dense mixtures, carefully placed and tamped, and an outer protection of timber.

"Deterioration of concrete structures is very slight at the Mare Island Navy Yard owing to the narrow range of temperature, low salinity of the water, and absence of ice or frost. In present quay wall construction Dr. Abram's methods of proportioning concrete are being followed with great care and the amount of water used reduced as far as practicable."

Committee Tests

The San Francisco Bay Marine Piling Committee has installed a large number of test pieces at several different localities in the Bay area. These test pieces have been prepared for the purpose of experimenting with

creosote either weakened by the subtraction or strengthened by the addition of the fractions of creosote.

Sixteen creosote combinations prepared by the Committee are under test as well as four sets of specimens prepared by the Forest Products Laboratory. These latter are impregnated with—

Barren oil.
Barren oil with 5 per cent B. Naphthol.
Barren oil 45 per cent., naphthalene 55 per cent.
Barren oil mercury treated.

Specimens are also under test of the following proprietary compounds:

Aczol.
Antimony trichloride in benzol.
Antimony trichloride in creosote.
Elaterite paints.
Moran preservative.
Paraffin.
Paraffin and arsenious iodide.
Paraffin and copper iodide.
Williams & Francois oil.

To the date of the last report the specimen treated with antimony trichloride and the one with Elaterite are the only ones of this series to be attacked after 10 months' immersion. It may be said in this connection that the attack of all the borers seemed much less intense in 1922 than previously.

Similar tests are being made with the following timbers:

Alder	Azobe
Greenheart	Tallow wood
Toledowood (Manbarklak)	Turpentine wood.

Chemical studies have been carried on upon the

"Extent and Character of Losses of Creosote Exposed Under Varying Conditions."

"Effect of Degree of Penetration on the Composition of Creosote."

"Observations of Test Pieces Treated with Inorganic Inhibitants."

"Effect of Chlorine Concentrations on Teredo."

"Effect of Various Salts in Protecting Wood."

The results of these studies, which are now being prepared for publication, will add materially to the knowledge of the protection of timber from marine borers.

Conclusions

Unprotected wooden structures in many portions of the San Francisco Bay area may not be expected to have a useful life exceeding one year, while in the Carquinez Straits territory life may be longer in years of heavy rainfall and consequent low salinity.

Coated piles may give a life of up to six or seven years, depending on the strength of the coating.

Creosoted fir piles properly impregnated and not damaged in handling or after driving may be expected to give an average life in excess of 15 years and in the Southern Pacific Long Wharf gave a service varying from 18 to 29 years with about 30 per cent showing some attack of *Limnoria* and molluscan borers.

Concrete armored wooden piles of some types seem to promise an average life of 15 years or more, but the age of existing structures is not great enough to permit accurate predictions to be made.

Concrete cylinder and reinforced concrete pile foundations are not of sufficient age to give the basis for accurate predictions, but serious deterioration does not seem to have generally set in on well built structures under 10 years of age.

The record of cast and wrought iron supports is excellent and such structures well designed may be expected to give a life of 40 years or more with comparatively little maintenance.

PUGET SOUND

Description

Puget Sound (Fig. 139) is a landlocked body of water, which contains several of the more important harbors of the Pacific Coast. It is entered from the Ocean through the Strait of San Juan de Fuca, which is about 82 miles long from Cape Flattery to Point Wilson. The Strait is from 10 to 30 miles wide and ranges in depth from 30 to 130 fathoms. On the south or United States side there are a number of harbors, few of which contain important marine structures. The general set of the currents is toward the north or Vancouver Island shore.

Puget Sound itself has a very irregular shore line, containing a large number of harbors and inlets, some of them of considerable size. The distance from Point Wilson to Seattle is, roughly, 32 miles, and from Point Wilson to Tacoma, 70 miles. Currents in Admiralty Inlet vary from 2 to 5 knots per hour, and are less in the more open waters near Seattle and Tacoma. The depth of water in the channels is great and in Elliott and Commencement Bays, the harbors of Seattle and Tacoma, respectively, there are depths of 50 to 80 fathoms. The extreme tidal range is from 17 to 19 feet. The result is that there is a considerable current close to the shore in these harbors, which aids in the distribution of marine borers, and these depths are also largely responsible for the small variation in temperature during the year. In general the water temperature, except in the shallow harbors, seldom gets below 50° Fahr. or above 55° to 58° Fahr.

There are a number of fair-sized rivers entering the Sound from the Olympic Mountains on the west and the Cascades on the east, but they have little influence on the salinity except in the immediate vicinity of their mouths.

Marine Borers

Past History—Records do not show any periods in the past when structures in the harbors of Puget Sound were not subject to attack by borers. The oldest structure of which a record has been found was a wharf built in 1877 by the Southern Pacific Company, which had its piles protected by copper sheathing, indicating that the danger was recognized at that time. There has always been a considerable amount of floating timber in all these

waters, which has undoubtedly assisted in maintaining a uniform and general distribution of borers.

It is generally agreed that an untreated pile will have a life of from six months to two years and therefore such piles are not used except for the most temporary structures.

Bankia setacea and *Limnoria lignorum* are the only wood borers so far known to exist, and are both exceedingly destructive.

Committee Investigations—Because of the known general distribution of borers and the generally uniform conditions as to salinity and temperature it was not considered necessary to place more than a few test boards in the Sound. They were all installed by the Bureau of Yards and Docks of the Navy, and are located as follows:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Keyport, Wash—Pacific Coast Torpedo Station	YD-1305	Navy	Jan. 16 1923	1.0	18.0
Receiving Ship Dock—Puget Sound Navy Yard	YD-1304b	Navy	Jan. 16, 1923	1.0	29.0
Pier No. 8—Puget Sound Navy Yard	YD-1304a	Navy	Jan. 16, 1923	1.0	34.0
Naval Ammunition Depot	YD-1306	Navy	Jan. 16, 1923	1.0	13.0

Figs. 140 to 143, inclusive, show salinity and temperature records at the test board locations.

The results of inspections of the blocks from these test boards are as follows:

YD-1305—The first specimens of *Limnoria* appeared on block 2, removed February 20, and the first of *Bankia* on block 5, removed April 1. One month later the largest of *Bankia* had reached a length of ¾ inch, and on June 1 about 3 inches. The number of specimens both of *Bankia setacea* and *Limnoria* was small and those of *Bankia* did not grow rapidly. The associated organisms were *Balanus* (very heavy growth), Bryozoa, Algae, *Mytilus* and some hydroids. The last test block inspected was removed January 16, 1924.

YD-1304 b—The first *Limnoria* appeared on block 4, removed March 16, and the first shipworm punctures on the next block two weeks later. The largest *Bankia setacea* on May 1 had reached a length of only 1 inch, and only about 35 specimens of *Limnoria* were found. From this time on the growth of the *Bankia* was more rapid, but the freedom with which they crossed from the blocks into the supporting board and vice versa made it very difficult to determine their length. The longest burrow found entirely in the block was in block 16, removed September 19, and was about 10 inches long. *Limnoria* attack was light and associated organisms were *Balanus* and hydroids. The last block reported was removed January 16, 1924.

YD-1304 a—The first specimens of *Limnoria* were found in block 4, removed March 16, and the first shipworm puncture in the next block, removed April 1. No others were found until block 9, removed June 1, which contained one *Bankia setacea* about 1 inch long. The next block two weeks later contained three animals, the largest about 4 inches long, while a length of over 9 inches was found one month later. The same difficulty existed in this board as in the preceding one in measuring the length of the

animals; one of the smallest in block 16, removed September 19, was nearly 5 inches long. *Limnoria* attack was light and associated organisms the same as on YD-1304 B.

YD-1306—The first *Limnoria* appeared in block 2, removed February 16, and the first *Bankia setacea,* which was nearly 3 inches long, in block 10, removed June 15. Some of the later blocks contained no specimens of *Bankia* and others only one or two, but the length of one animal found in

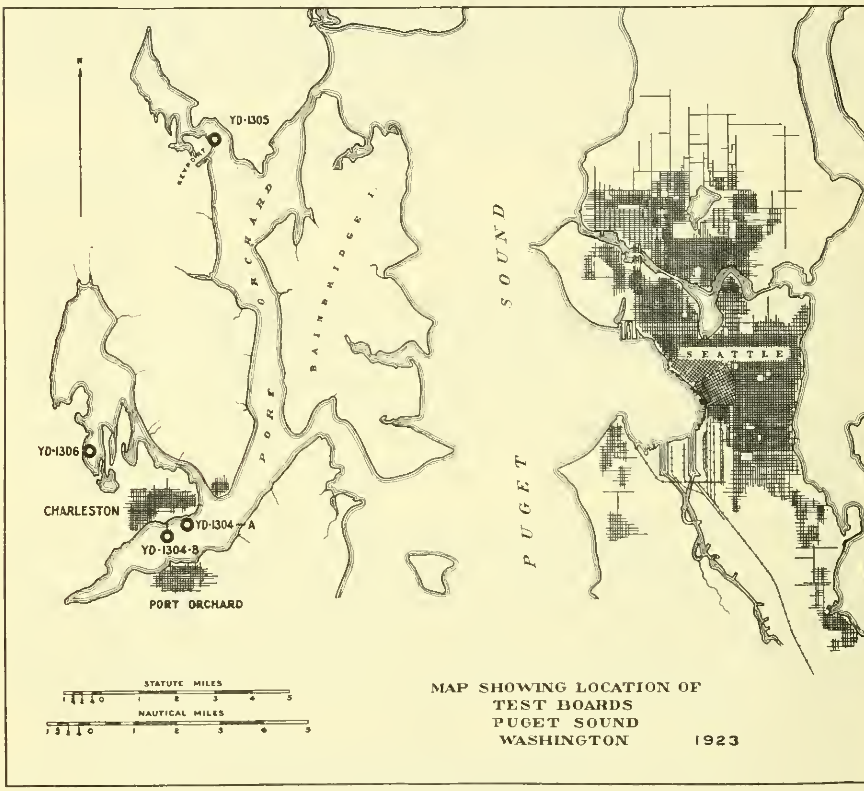


Fig. 139

block 18, removed October 16, was over 17 inches. *Limnoria* attack was light. Associated organisms were *Balanus,* Bryozoa, *Mytilus* and hydroids.

Methods of Protection

Pile Coatings—Some use has been made of various preservative paints and the same results obtained as at other ports, i. e., this method of protection is of only temporary value, even with the best of preservatives.

Creosote Impregnation—Treatment by impregnation with creosote has been practiced for many years. The first process was by use of the open tank where the piles were boiled in creosote under atmospheric pressure. Some piles treated by this process gave good service, lasting about 20 years, but since douglas fir, which is the only timber in general use in this terri-

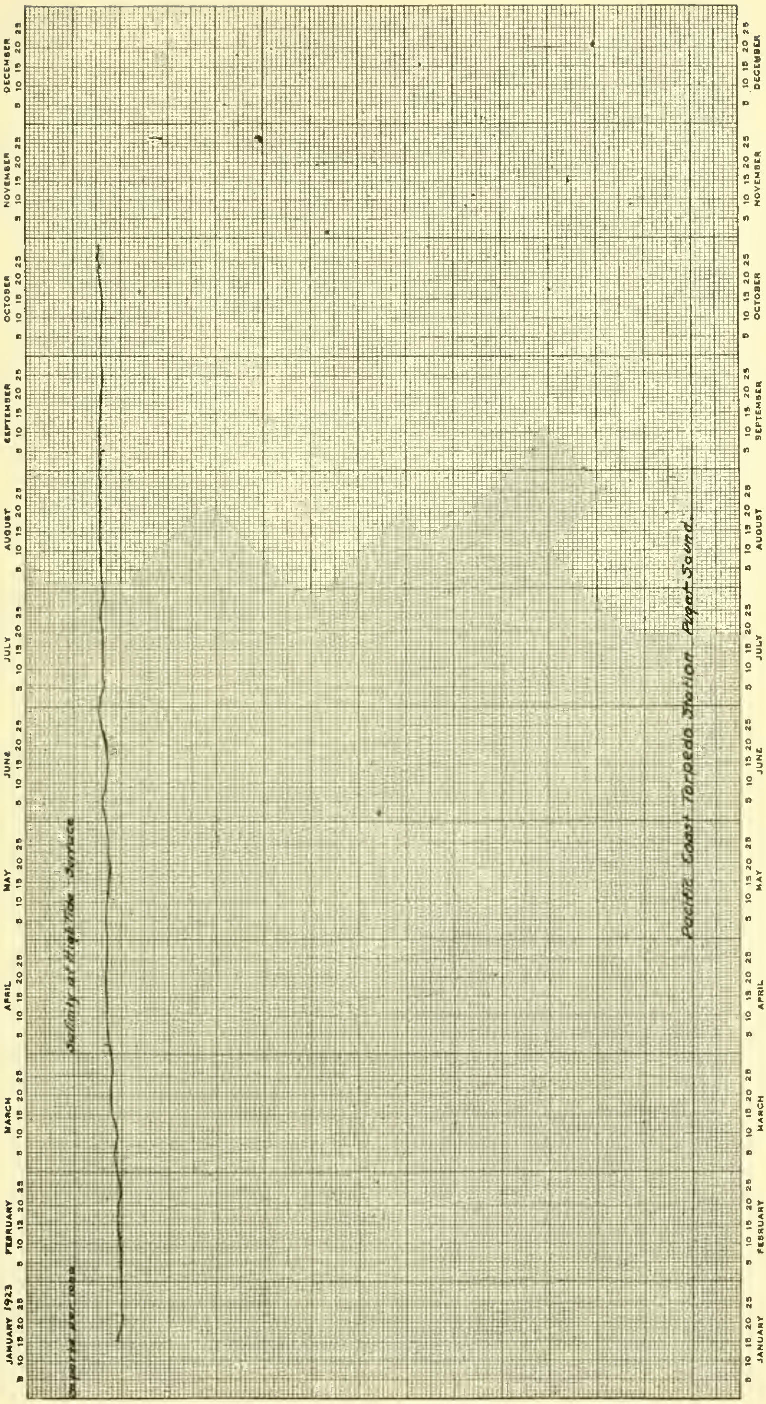


FIG. 140—SALINITY OF WATER AT PACIFIC COAST TORPEDO STATION, PUGET SOUND NAVY YARD

tory for construction purposes, is very hard to impregnate, the average life was not satisfactory.

The present method of treatment generally involves boiling under vacuum and impregnation under pressure. With this method and the use of a good quality of creosote an average life of 12 to 16 years may be expected, but on account of the variation in the resistance of this timber to treatment a certain percentage of failures can be expected in considerably less time. For example, the Oregon-Washington Railroad & Navigation Company report a structure built in 1917 on piles with 12 pounds of creosote per cubic foot showing attack in 1922.

At the Pudget Sound Navy Yard all "permanent" structures are supported either on creosoted piles or are of concrete construction, the amount of creosote injected being generally about 12 pounds per cubic foot. No oil analyses are available. There follows a list of the Navy Yard piers on creosoted piles:

Name of Pier	Date Built	Dimensions	Bracing	Condition
Receiving Ship Pier.	1920	972'x22' to 32'.	Spiked......	Unattacked March 5, 1923.
Coal Wharf........	1915 and 1923	700'x57' to 94'	Batter Piles. Untreated.	Unattacked March 5, 1923. Braces riddled.
Sand and Gravel Pier	1921	104'x48'......	Bolted......	Piles good March 6, 1923.
Approach to Pier 4.	1914	210'x40' to 97'.	....	Unattacked March 7, 1923.
Pier 5............	1914	505'x80'......	....	Rebuilt 1923. 82 piles reported all attacked, *Bankia* only in damaged piles, slight *Limnoria* attack in others.
Pier 6	1912-1914	529'x49'......	Batter Piles.	Unattacked March 7, 1923.
Pier 7............	1904	502'x57'......	Batter Piles	40 per cent piles replaced 1920 in 350' length.
Extension Pier 8....	1914	100'x60'......	Batter Piles.	Unattacked March 9, 1923.

All creosoted piles now being used at the Yard are treated in accordance with the specifications of the San Francisco Bay Marine Piling Committee. The usual length of piles used is between 45 and 65 feet, and the cost in 1923, untreated, averages about 16 cents per foot, while creosoted piles cost from 65 cents per linear foot for piles 45 to 65 feet long to 85 cents for those between 75 and 90 feet.

Pile Armors—The "Perfection" process seems to have been first used in 1895 in a dock at Tacoma. This process is described on page 95.

Metal—In 1877 the Southern Pacific Company built a wharf at Tacoma on copper sheathed piles; when this dock was removed in 1898 the piles were in excellent condition and were re-used in other structures. Forty-four of them are still in service in a bridge and reported to be in good condition, though the copper was removed in 1898 when the piles were taken out of salt water.

Iron cylinders surrounding clusters of piles were used in two Northern Pacific structures in 1882, and were found in 1910 to be corroded to such an extent that borers had heavily attacked the piles.

Concrete—An interesting method of protecting piles with concrete has been used in the construction of the new piers by the Port of Tacoma Commission. A concrete casing was built with a cement gun on the pile before driving, and the piles were handled very carefully to prevent fracture of the coating on account of flexure of the pile. This work was done in 1921 and it is, of course, too soon to make any prediction as to its durability.

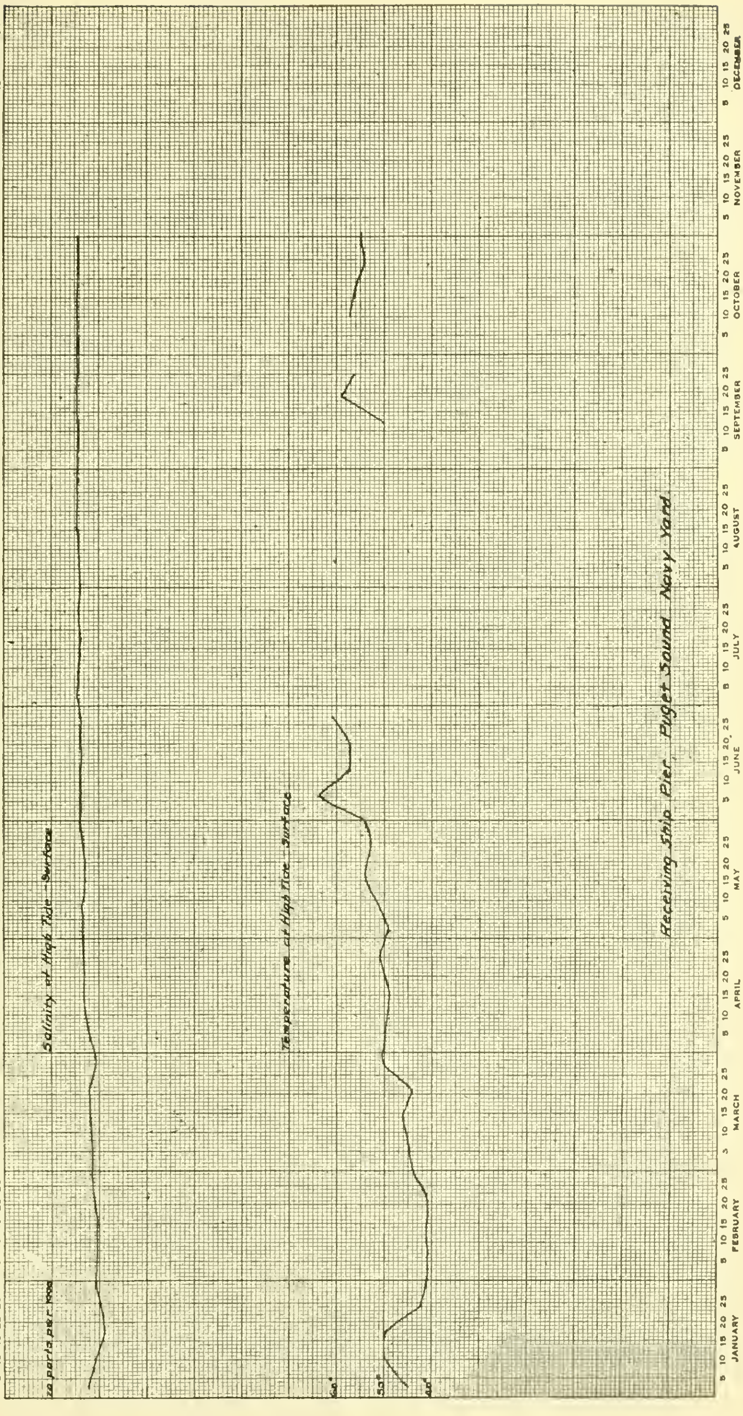


FIG. 141.—SALINITY AND TEMPERATURE OBSERVATIONS, RECEIVING SHIP PIER, PUGET SOUND NAVY YARD

A similar method of protection was used by the Pacific Northwest Traction Company on one of their structures located above low tide near Bellingham, Wash. This trestle, about 5 miles long, was built with white cedar piles in 1911. It was heavily attacked by *Limnoria.* In 1916 concrete casings were built from a point 6 inches below to 18 inches above the mud line, but the *Limnoria* attack continued above this point. Next a wash of cement and sand was applied without removing the barnacles on the pile, which was effective for about two years. In 1918 the piles were scraped clean, covered with mesh reinforcement and a cement gun coating about ¾ inch thick applied. The holes dug into the piles by *Limnoria* were filled out at the same time. These piles are reported to be in good condition at the present time.

The new municipal piers at both Seattle and Tacoma are built with an earth or sand fill in the center with aprons supported on piles on the slopes to carry the outside walls of the warehouses and the railroad tracks on the face of the pier. In Seattle creosoted piles are used and in Tacoma both creosoted and gunited piles.

Substitutes for Timber

Concrete—There are a number of concrete structures at the Navy Yard, and while most of them are of too recent date to give service records of value, the description of the construction methods will be of value to later investigators.

Pier No. 8, 403 feet by 60 feet, was constructed in 1911 on reinforced cylinders, spaced 16 feet longitudinally and transversely. The deck is formed of I-beams with an 8-inch reinforced slab floor finished with a 1-inch granulithic surface.

These cylinders had 3 15/16-inch walls reinforced with 1-inch round rods and "Hy-Rib" with 2-inch cover over the reinforcing. The mixture was 1:2 cement mortar. After the cylinders were sunk to place the bottom was sealed, the water pumped out and the cylinders filled with 1—variable—4 concrete. The specifications provided that the quantity of sand should be such as would produce the greatest density. Forms were removed 48 hours after completion of the cylinders and a 30-day curing period was observed. Fresh water and cement manufactured by the Santa Cruz Portland Cement Company were used and all reinforcing was carefully cleaned.

In April, 1921, some deterioration in both the cylinders and deck girders and slabs, generally in construction joints, was found and was repaired with "Gunite" above a point 2 feet above high water.

An inspection of the superstructure on March 9, 1923, showed some additional deterioration, but the "Gunite" repairs made in 1921 were generally in good condition.

Pier 4—This pier is supported on cylinders cast in place in 1913-14, and has a timber approach. The concrete portion is 490 feet by 80 feet, and the cylinders are spaced 20 feet transversely and 30 feet longitudinally. The deck is constructed with reinforced concrete girders and stringers with an 8½-inch slab floor.

The cylinders, 4 feet in diameter, belled to 11 feet at the bottom, are supported by wooden piles. The wooden watertight forms were sunk to place, sealed, pumped out, the reinforcing placed and the concrete carefully deposited and spaded around the reinforcing, a 2-inch cover being main-

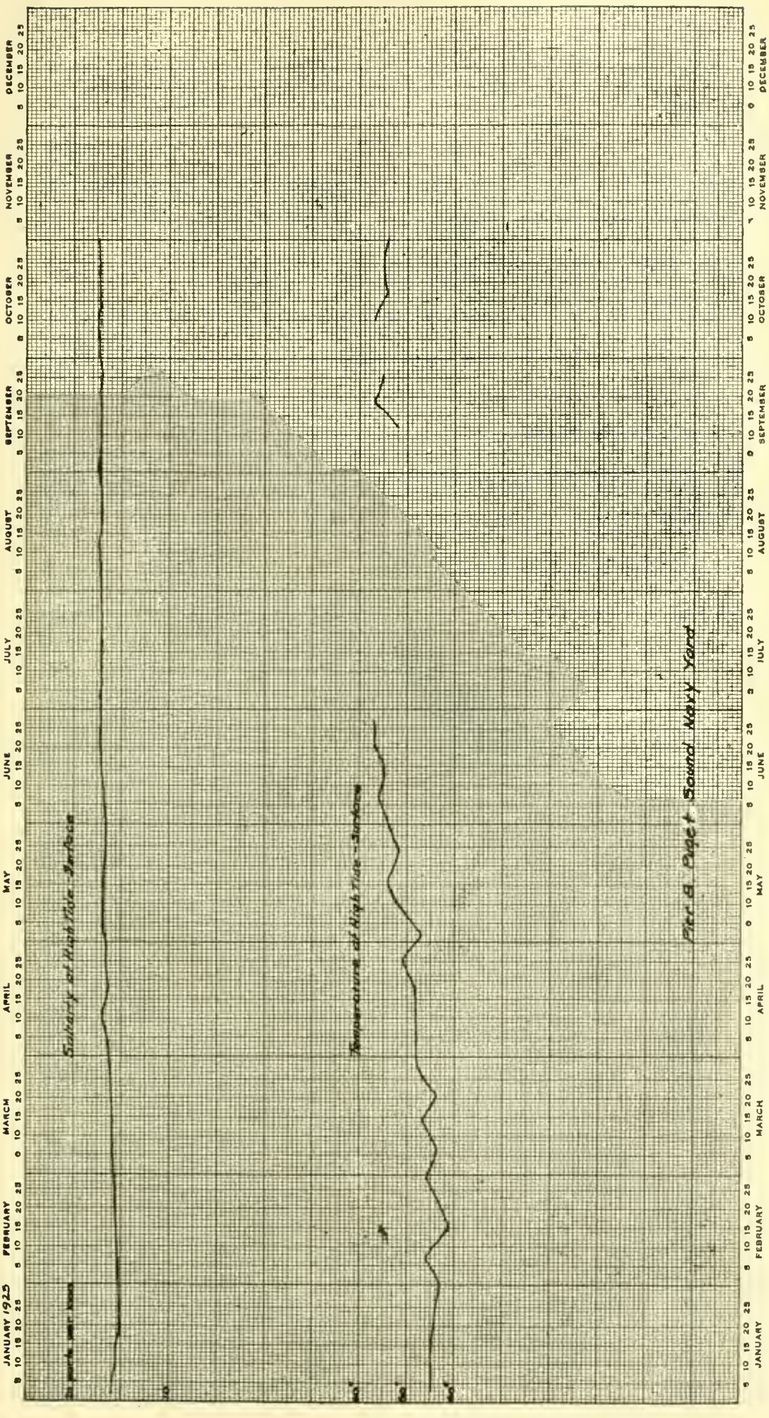


FIG. 142—SALINITY AND TEMPERATURE OBSERVATIONS, PIER 8, PUGET SOUND NAVY YARD

tained. The reinforcing, which was carefully cleaned, consisted of ⅝-inch rods 4 inches by 8 mesh and "Hy-Rib." The concrete mixture was 1:2:4 with the upper 6 feet containing "Truscon paste" as an integral waterproofing compound, in quantity equal to 2 per cent of the cement.

Minor disintegration was found above water level in 1921 in both cylinders and deck and was repaired with "Gunite." An inspection of the underwater portion of the structure in September, 1923, disclosed some disintegration, and some large crabs (*Oregonia gracilis* Dana) and (*Cancer productus*) were found in the holes. The diver reported that these crabs when found were pecking at the concrete, but it is not thought that they had anything to do with the disintegration.

Pier 5—The pier under construction in 1923 is 1,200 feet by 80 feet, supported on pre-cast cylinders 4 feet and 4 feet 6 inches in diameter, with wall thicknesses of 6 inches and 8 inches, respectively. It was found impossible to seal the bottoms, so they are being filled under air pressure.

The reinforcing, which was carefully cleaned, consists of square bars, No. 20 wire mesh and spiral hooping with not less than 2-inch cover. The concrete mixture is 1:2:2 and a 1:3¾:4¼ mixture for filling, using sand, gravel and Olympic cement with a consistency such that the concrete flowed freely.

The curing period has been five weeks, and the cylinders were sprinkled daily during this period.

The deck is of the girder, beam and slab type, using a 1:2¾:4¼ mixture. For both deck and cylinders, Professor Abrams' method of proportioning was used, the water amounting to about 4 gallons per sack of cement.

Seawall—This structure under construction in 1923 is 1,200 feet long and consists of wooden bearing and brace piles enclosed by reinforced concrete sheet piling and surmounted by columns carrying the usual girder and slab deck construction.

The proportioning of the mixture for the sheet piles was done in accordance with the system devised by Professor Abrams, and resulted in an average of about 1:1¼:2 and about 3½ gallons of water per sack of cement for fairly dry aggregate. The aggregate was sand and gravel with Olympic cement.

Piles were kept wet for seven days and seasoned over 30 days, after which they were driven with a 4,535-lb. drop hammer and two jets under 250 pounds pressure. Reinforcing was 1-inch round rods, and the proportion of section for 18 by 18 inch piles 30 feet and under in length was 1.94 per cent, and for 18 by 20 inch piles 30 feet to 50 feet was 1.74 per cent, in all cases with over 2-inch cover.

The method of proportioning, materials, etc., was the same for the columns and deck as for the sheet piles.

Quay Wall A—This is a reinforced wall 1,190 feet long, of counterpart type, built in 1905-06 inside a cofferdam.

The mixture was 1:3:6 with a 1:2 mortar facing. The lower 6 feet of the wall was placed in the dry, but the tide frequently covered the remainder, which was carefully cleaned and grouted before recommencing work. The wall has been repaired at various times, and in March, 1923, showed considerable deterioration.

Quay Wall C—This wall, about 335 feet long, of gravity type mass con-

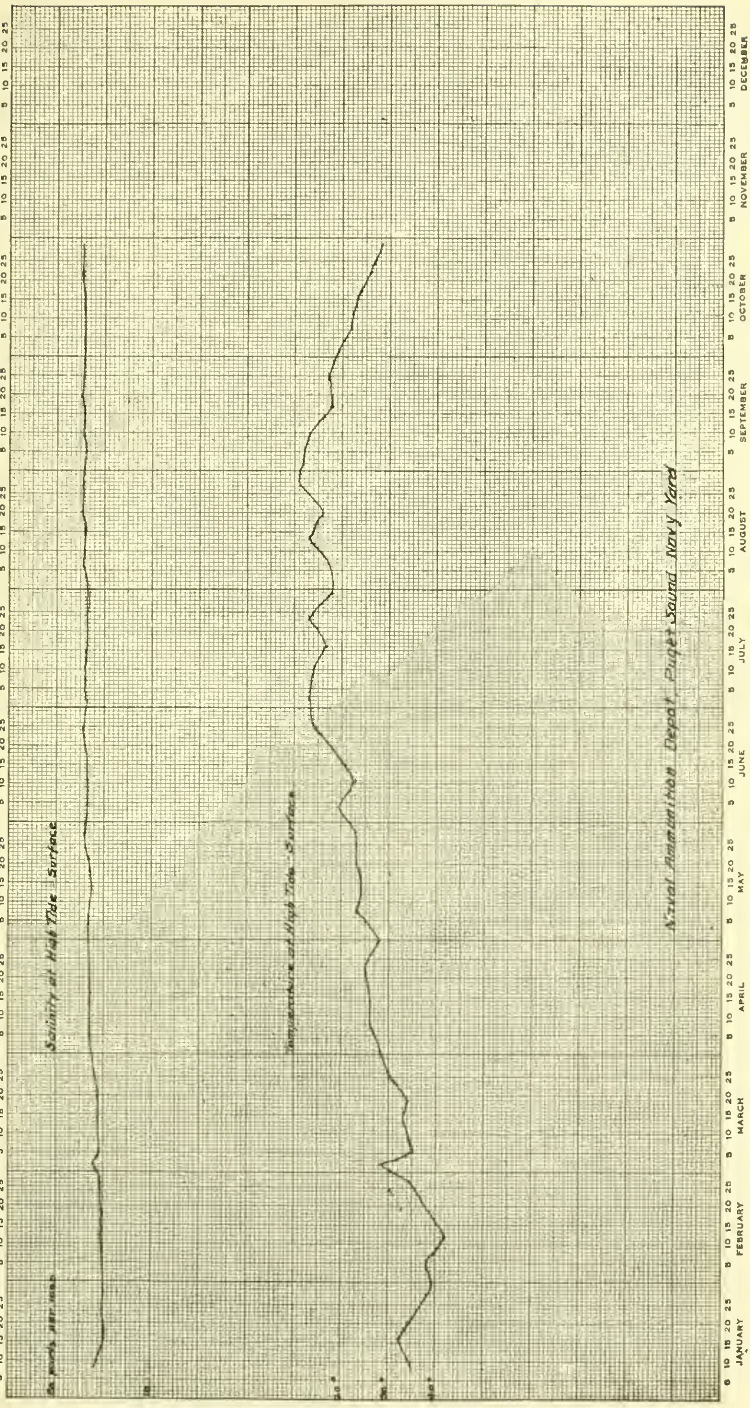


FIG. 143—SALINITY AND TEMPERATURE OBSERVATIONS, NAVAL AMMUNITION DEPOT, PUGET SOUND NAVY YARD

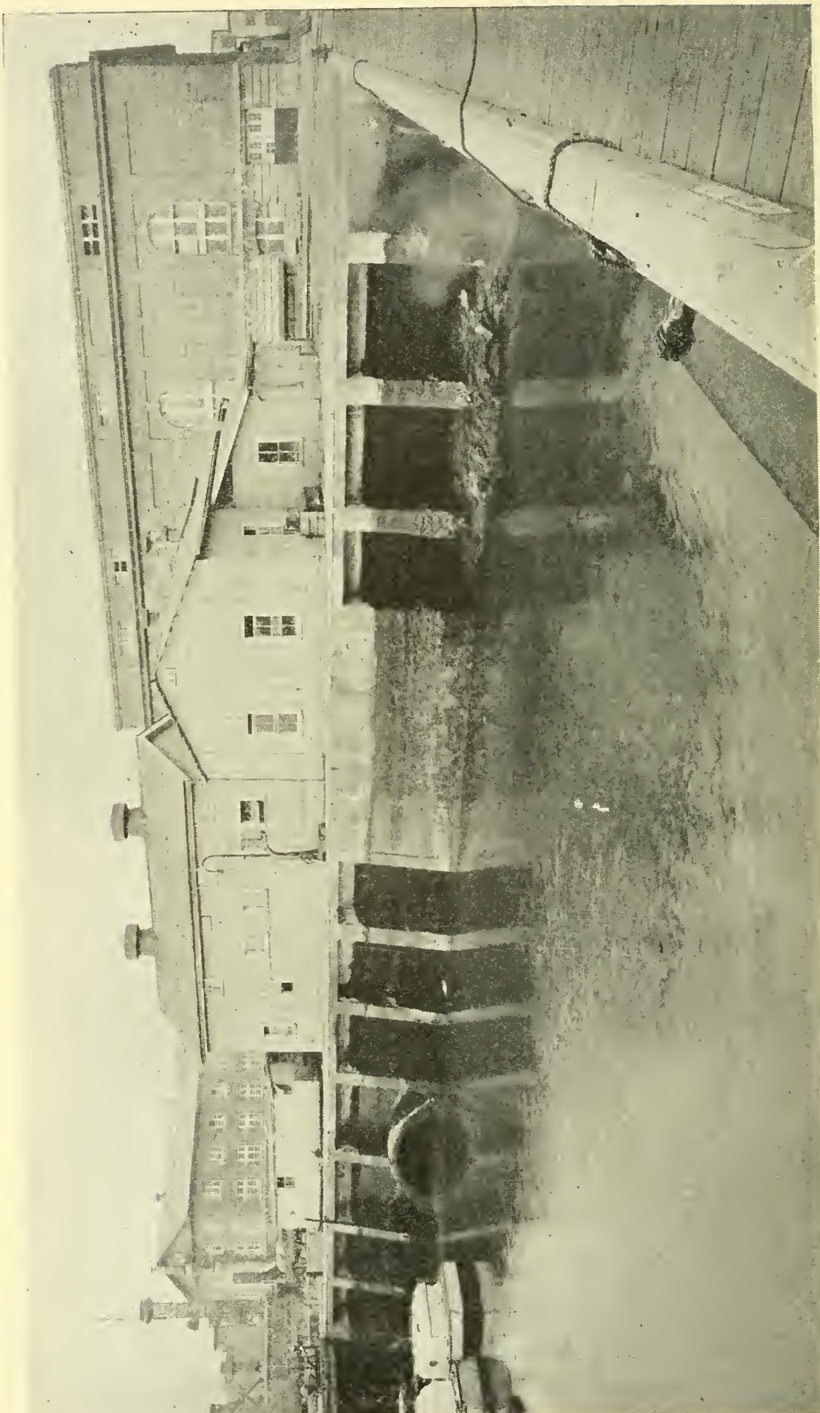


Fig. 144—Seawall Section, Puget Sound Navy Yard, Showing Concrete Disintegration

crete, was built in 1908-13. Materials used were local sand and gravel and "Golden Gate" cement with a granolithic facing.

In general this wall was in good condition on March 7, 1923, except for a few temperature cracks where disintegration had commenced.

Quay Wall D—This is a gravity type wall, built in 1901-02. Local aggregates and "Condon" cement were used in the proportion of 1:2½:5. This concrete was hand mixed and deposited below water level by tremie and above with wheelbarrows.

The inspection of March 8, 1923, showed this wall to be badly deteriorated, though "Gunite" repairs had been made.

Quay Wall E—This wall, of the gravity type, 180 feet long, was constructed in 1895-96, using local aggregates and K. B. & S. English cement in the proportion of 1:2:4. It has deteriorated considerably between high and low water.

Several other walls and structures are reported, but generally of the same type of construction and in about the same condition (Fig. 144).

Conclusions

No structure in the waters of Puget Sound should be constructed with untreated piles if it is expected to last over one year, and it may fail in less time if it be constructed in May or June.

The period of immunity from *Bankia* attack probably covers the fall and winter months of the year, but there is no apparent period of immunity from *Limnoria.*

Thoroughly creosoted douglas fir piles may be expected to have an average life of from 12 to 16 years.

The only concrete structures reported are those at the Navy Yard, and while the older structures show deterioration they were not built under specifications which would be considered good practice today.

BRITISH COLUMBIA

No test boards have been maintained or records systematically collected in British Columbia waters, but it is stated by the scientists of the Biological Laboratory of the Bureau of Marine and Fisheries of the Dominion, that in the vicinity of the laboratory at Departure Bay, *Bankia setacea* and *Limnoria* are very destructive and that *Exosphaeroma oregonensis* is also present.

Salinity readings are shown on Fig. 145. The mouth of the Fraser River is directly across the Strait from the laboratory, and when in flood the fresh water discharged by it is in sufficient quantity to materially affect the salinity at the latter location.

ALASKAN COAST

Description

The coast line of Alaska, 25,000 miles in length, contains many fine harbors, but on account of lack of industrial development, it did not seem necessary or desirable to make a detailed study of any of them. Practically all the Pacific harbors on the south coast of Alaska and those of the Aleutian Islands have some conditions in common; their depth is great, the tidal range is considerable and the water temperatures have only small seasonal variations, and while there are large streams entering some of them the depths are so great that the effect of the streams on the salinity does not generally extend any great distance from their mouths.

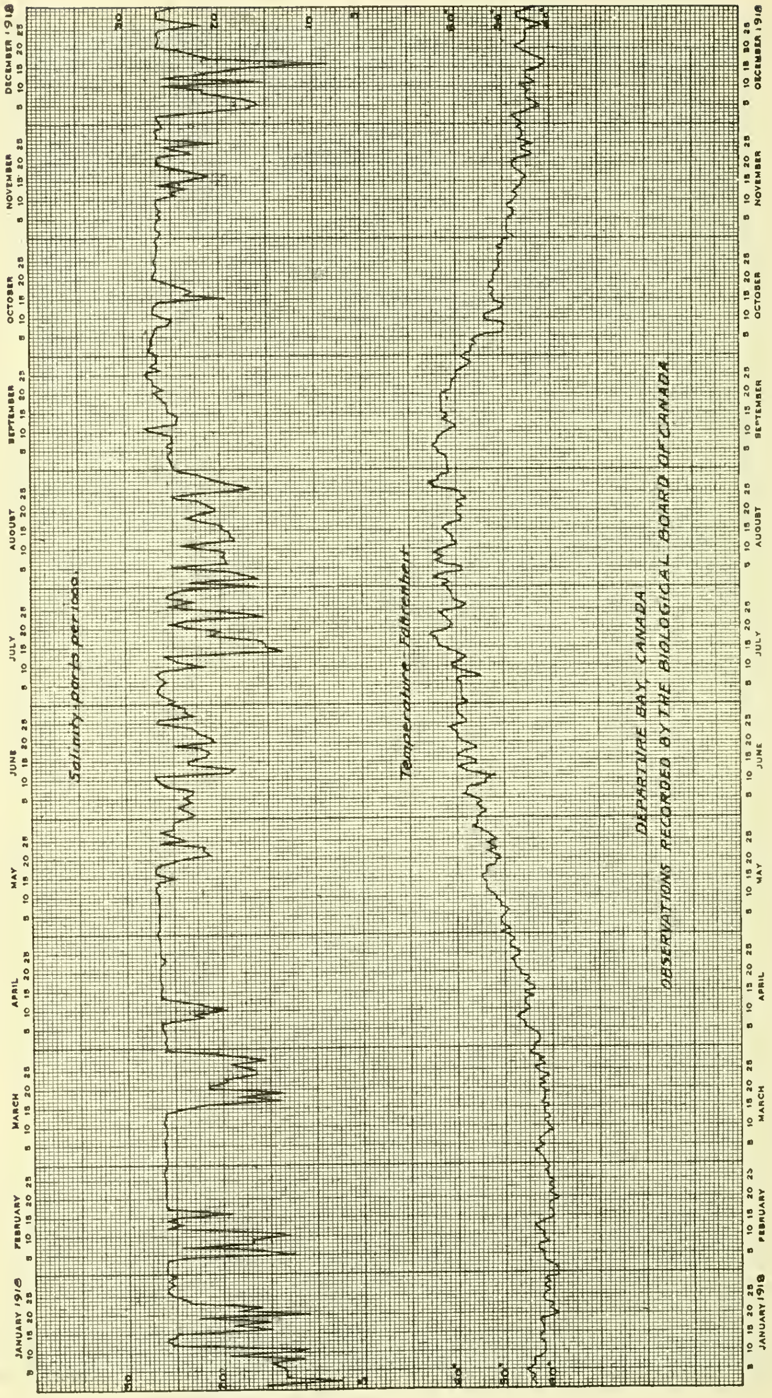


Fig. 145—Salinity and Temperature Observations, Departure Bay, Vancouver Island

Ketchikan (Fig. 146), 649 nautical miles from Seattle, the southernmost important port, is located in the extreme southeastern corner of the Territory on Tongass Narrows. The wharves extend to deep water and the depth 200 to 300 yards off the wharves is from 8 to 20 fathoms. The tidal currents do not exceed 1½ to 2 knots per hour. The maximum range of tide is about 23 feet.

Petersburg (Fig. 147), 778 nautical miles from Seattle, is a small village about one mile south of the north end of Wrangel Narrows. The depth of water at the wharves is only 12 feet at low water, and the tidal current

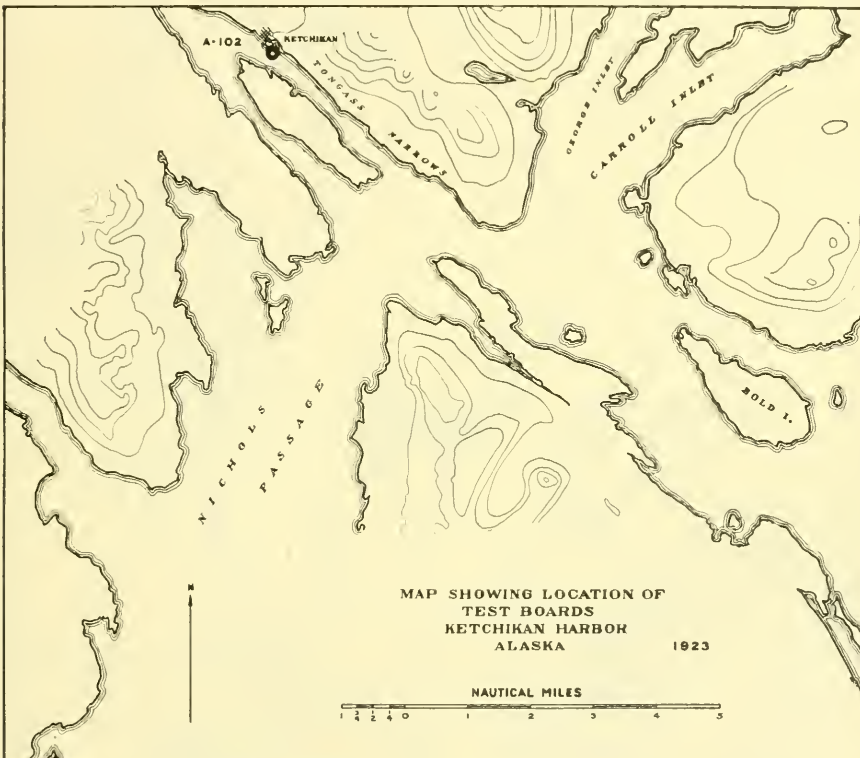


Fig. 146

which flows past the end of the wharves has a velocity of somewhat over 4 knots per hour, with a maximum tidal range of 20 feet.

Juneau (Fig. 148) 886 nautical miles from Seattle, is an important mining town and the capital of the Territory. It is located on the northeasterly side of Gastineau Channel. There are several wharves with a tidal current passing them of about 2 knots per hour. Very heavy gales occur, but the channel is so narrow that there is very little sea. Depths in the fairway are about 20 fathoms, and the maximum tidal range is over 21 feet.

Sitka (Fig. 149), the former capital of the Territory, is located on Baranoff Island, 59 miles west of Juneau. It is located on a large bay studded

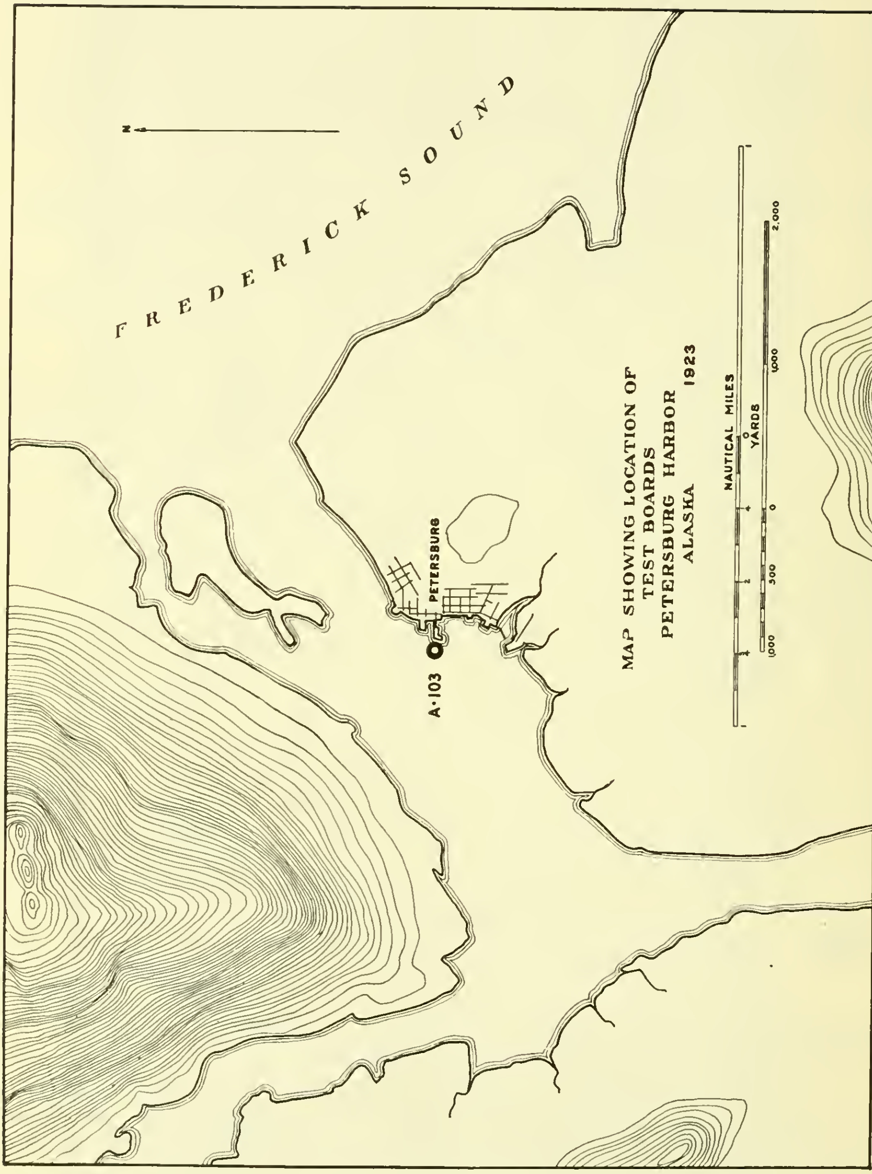

FREDERICK SOUND
PETERSBURG
A·103
MAP SHOWING LOCATION OF
TEST BOARDS
PETERSBURG HARBOR
ALASKA
1923
NAUTICAL MILES
YARDS

Fig. 147

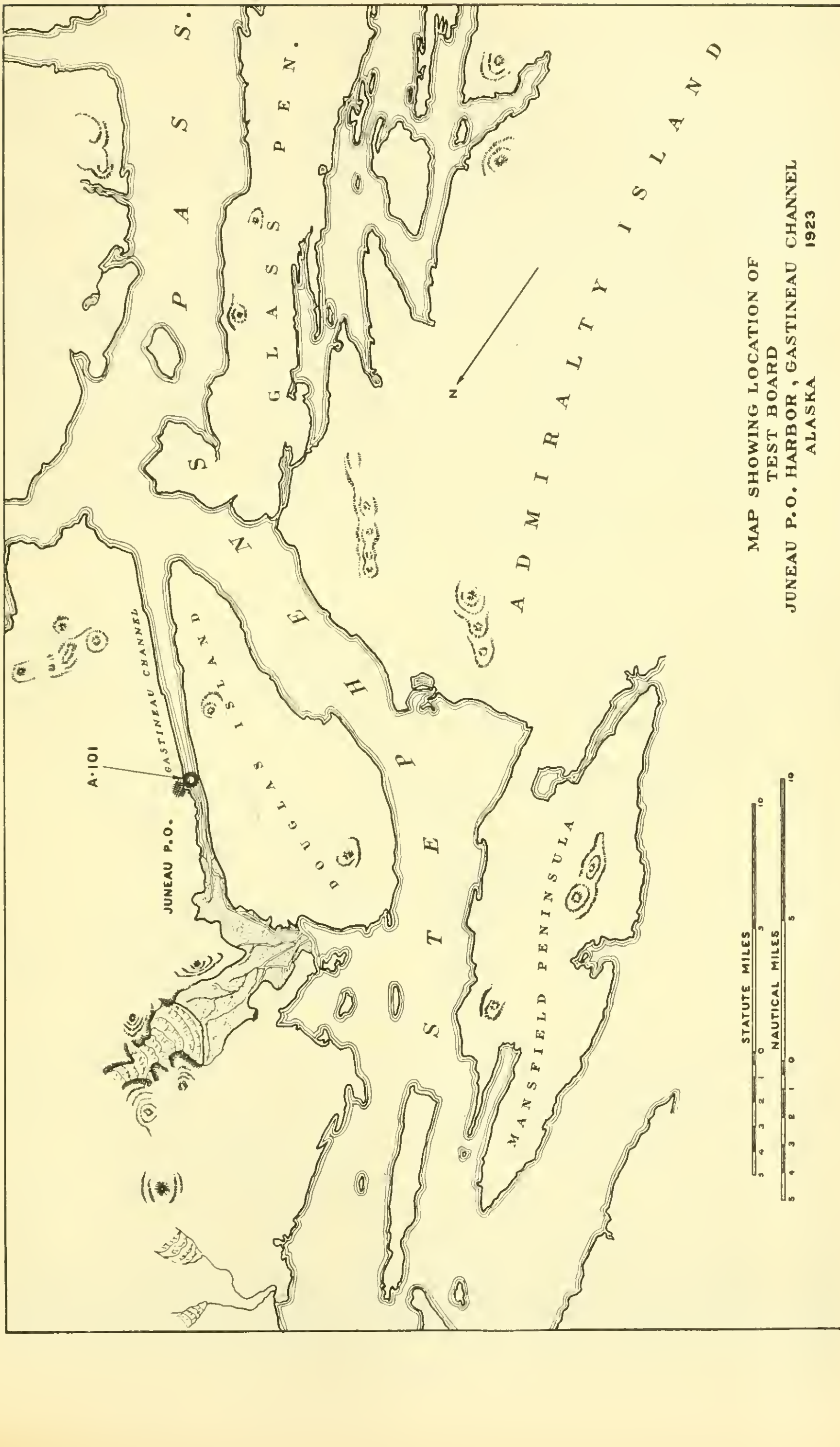

MAP SHOWING LOCATION OF
TEST BOARD
JUNEAU P.O. HARBOR, GASTINEAU CHANNEL
ALASKA
1923
STEPHENS PASSAGE
GLASS PEN.
DOUGLAS ISLAND
GASTINEAU CHANNEL
A·101
JUNEAU P.O.
ADMIRALTY ISLAND
MANSFIELD PENINSULA
N
STATUTE MILES
NAUTICAL MILES

FIG. 148

with islands. There is a depth of 24 feet at the city wharf and 28 feet at the Naval Wharf on Japonski Island. The general depth of the Bay is from 5 to 9 fathoms. Tidal currents are about 2 knots at the wharves with a maximum range of about 13 feet.

Seward (Fig. 150), about 1,200 miles by great circle route and 1,900 by the coastwise route from Seattle, is located about 2 miles from the head of Resurrection Bay and 16 miles from the ocean. It is the ocean terminus of the Government railway. The railroad wharf has a depth of 30 feet at its face and the Bay as a whole has depths up to 160 fathoms. The tidal range is about 20 feet and the currents at the dock are negligible.

Kodiak (Fig. 150) is a small village on St. Paul Harbor, Chiniak Bay, on the northeastern end of Kodiak Island; the channel is narrow and crooked; the depth at the wharf is about 27 feet and in the channels and anchorage 8 to 30 fathoms. The tidal current at the wharves is about 2 knots and the maximum range 13 feet.

Dutch Harbor (Fig. 151) and Unalaska are on Unalaska Island, the largest of the Aleutian Islands, about 1,800 nautical miles by great circle course from the straits of Fuca. This is the most important harbor in Western Alaska. It is a large nearly landlocked bay with depths of from 6 to 10 fathoms in the upper portion. The tidal range is about 2 feet and the currents negligible. The depth at the wharf at Unalaska is 25 to 36 feet.

Marine Borers

Past History—No record of a biological survey of this coast has been found, but reports secured by the District Engineer, U. S. E. D., the Lighthouse Superintendent and the Bureau of Yards and Docks, show the following information obtained from wharf owners:

Location	Kind of Borers	Estimated Life of 16″ Pile
Ketchikan	Teredine	Peeled—1 year.
	Limnoria	Tight bark—3 to 4 years.
Wrangel*	Teredine	2 years.
Juneau and Douglas Id	Teredine	2 to 6 years.
Haines Mission (Ft. Seward)†	Teredine	4 years.
Skagway†	Teredine	7 years (Hemlock unbarked.)
Cordova (C. R. & N. W. R. R.)‡	Teredine	8 months. (Spruce barked).
	Limnoria	2 years (Unbarked hemlock).
Valdez‡	Teredine	10 to 14 months.
Seward	Teredine	8 months to 1 year.
Anchorage§	None	Oldest piles 7 years.
Kodiak	Teredine, Limnoria.	3 years.

*Wrangel is a small village near the south end of Wrangel Narrows between Ketchikan and Petersburg.

†Haines Mission and Skagway are located on Lynn Canal about 80 and 100 miles respectively east of Juneau. Tidal range is high and currents are strong.

‡Cordova, the terminus of the Copper River and Northwestern Railroad, and Valdez, are on Prince William Sound between Sitka and Seward. Tidal range is greater at Valdez and less at Cordova than at Seward.

§Anchorage is on Knik Arm of Cook Inlet where the water is nearly fresh and, on account of excessively high tidal range, strong currents and shallow water, there is a great amount of suspended silt.

There had been no timber structures in Resurrection Bay since the abandonment of the Russian Shipyard early in the nineteenth century. The wharf of the Alaska Central Railroad (now the U. S. Government Railroad), built in the winter of 1903-4 with native spruce piles, collapsed under a load not exceeding 500 tons in 1905 on account of the attack of teredine borers. The piles were as thoroughly honeycombed as it is possible for piles to be.

Pile dolphins at Ketchikan were destroyed by *Limnoria* alone between 1915 and 1921.

Committee Investigations—Standard test boards were placed at the following locations:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Ketchikan—Dock No. 13, Forest Service	A-102	Army	Nov. 4, 1922	1.0	30
Petersburg—Cannery Wharf	A-103	Army	Nov. 1, 1922	0.0	15
Juneau–Old Pacific Coast Steamship Wharf	A-101	Army	Oct. 15, 1922	1.0	22
Sitka—Naval Wharf, Japonski Island	YD-1303	Navy	April 1, 1923	1.0	19
Seward—Government R.R. Wharf	A-104	Army	Nov. 6, 1922	0.0	18
Kodiak—W. J. Erskine Wharf	A-105	Army	Dec. 1, 1922	0.0	18
Dutch Harbor (Unalaska)—A. C. Co. Wharf	YD-1301	Navy	Dec. 15, 1922	1.0	......

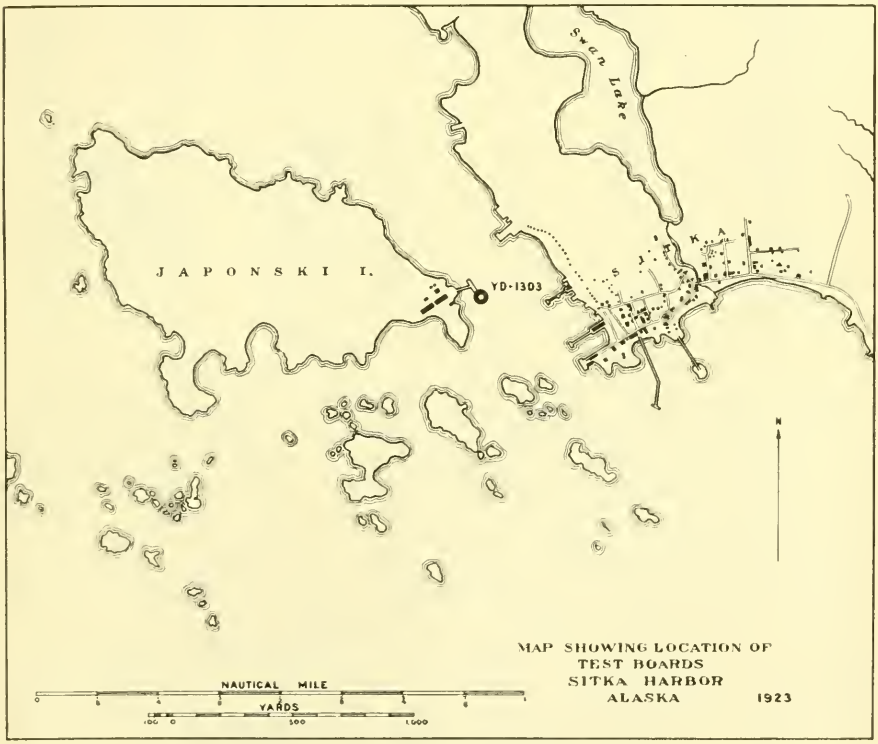


FIG. 149

A-102—One specimen of *Limnoria* appeared on the first block, removed November 16, 1922. Block 7, removed February 16, 1923, showed 25 of *Limnoria* and one of *Bankia setacea* about 2 inches long; on block 9, removed March 16, there were 115 specimens of *Limnoria* and four of *Bankia*

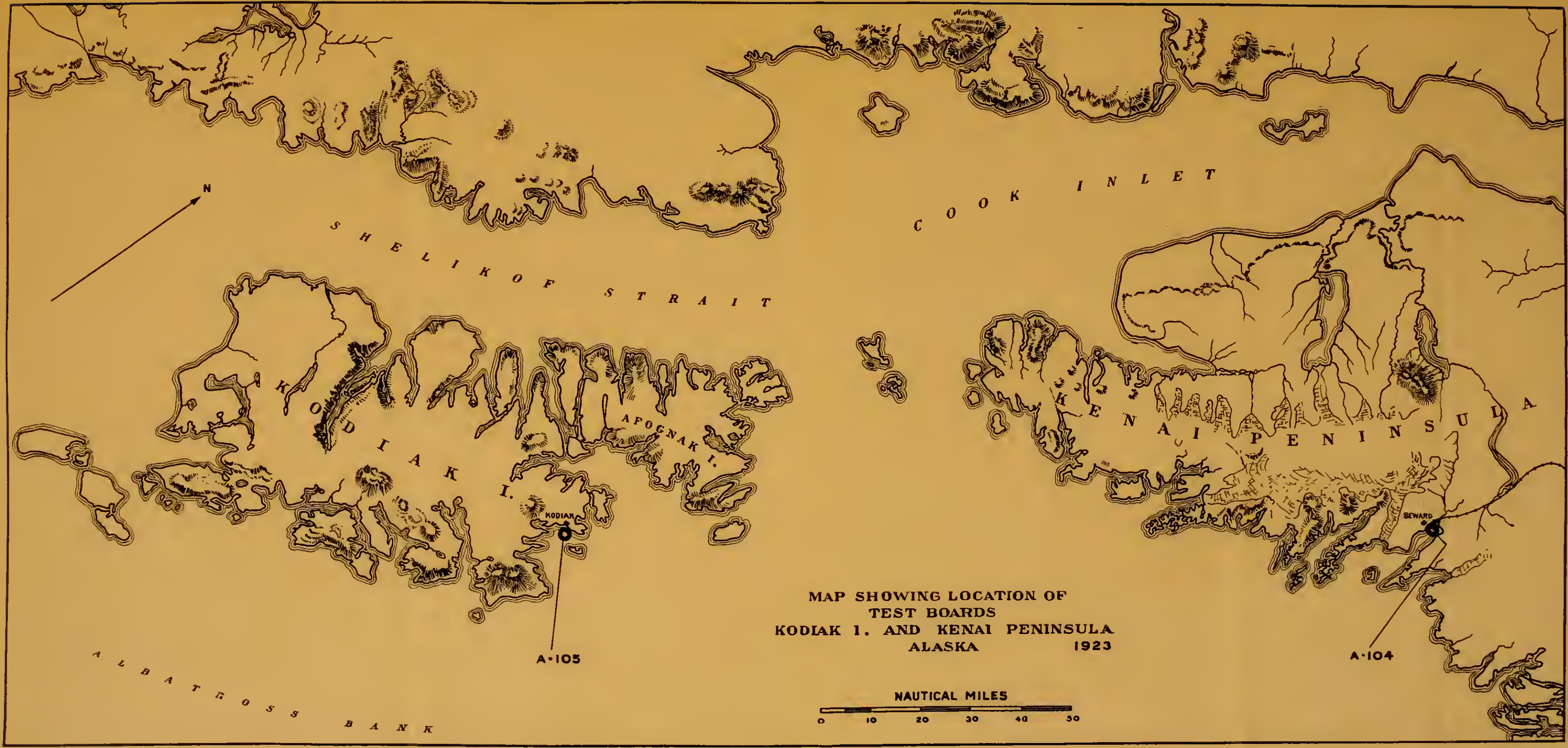
setacea, the largest about 2 inches long and ⅜ inch in diameter. These numbers had increased on block 11 one month later to 140 of *Limnoria* and 12 of *Bankia setacea,* the largest about 3½ inches long. The severity of the attack of both *Bankia* and *Limnoria* increased until by October 1 the blocks were completely honeycombed. *Bankia* specimens 8 inches long were found, but since many of them crossed from the blocks into the board it is probable that much larger animals existed. Associated organisms were Bryozoa and tube worms.

Temperatures and salinities are reported by the Coast and Geodetic Survey as follows, water samples being taken from the pier on which the test board was located:

Year	Month	Temperature—° Fahr.			Salinity at 60° Fahr. Parts Per 1,000		
		Mean	Warmest	Coldest	Mean	Greatest	Least
1921....	November...	42	44	39	26.7	27.9	25.8
	December...	43	44	41	25.0	28.2	21.0
1922....	January....	42	43	41	No hydrome	ter readings t	aken.
	February...	41	43	39	No hydrome	ter readings t	aken.
	March......	41	42	41	26.2	30.2	27.2
	April.......	42	43	41	29.4	30.2	27.6
	May.......	44	52	43	26.7	29.4	22.9
	June.......	53	57	50	24.8	27.4	21.0
	July........	54	59	50	27.4	28.8	26.0
	August.....	56	59	54	26.2	28.4	24.1
	September..	53	54	50	23.8	27.2	14.2
	October.....	48	50	44	23.7	27.7	16.6
	November..	44	47	43	22.2	26.6	14.0
	December...	40	44	38	26.2	29.4	22.7
1923....	January....	41	43	39	28.9	30.0	27.0
	February...	41	43	38	29.0	30.2	27.2
	March......	41	42	39	27.9	30.0	20.8
	April.......	43	47	42	26.8	30.0	19.6
	May.......	47	50	43	25.2	29.7	19.6
	June.......	55	61	48	24.1	26.5	21.6
	July........	58	61	56	24.0	25.8	21.4
	August.....	59	61	55	24.0	26.0	15.2
	September..	54	57	51	23.2	26.5	15.4
	October.....	50	53	46	24.6	26.8	22.6
	November..	45	49	43	22.1	24.9	15.2

A-103—*Limnoria* appeared on the second block, removed December 1, 1922, and several minute shipworm punctures on January 2, 1923; on February 1, 1923, the number of specimens of both *Limnoria* and *Bankia setacea* had not increased appreciably and the largest of the shipworms was only 3/16 inch long; on block 8, removed March 3, the number of specimens of both *Limnoria* and *Bankia* had increased and the largest *Bankia* was ½ inch long; block 12, removed May 23, showed about 200 specimens of *Limnoria* and probably 50 of *Bankia,* the greatest length being about 2 inches. No associated organisms except tube worms were found.

A-101—At Juneau the first specimens of *Limnoria* did not appear until block 5, removed January 1, 1923, 2½ months after the immersion of the board. This attack increased gradually until block 23, removed October 1, was so heavily attacked that the surface had crumbled. The first shipworm punctures appeared on block 8, removed February 15, but on later blocks few, if any, were found until block 12, removed April 16, which contained five specimens of *Bankia setacea* up to ⅜ inch in length. No more were found until block 17, removed June 30, when they had reached a length of over 2 inches. From this time on the number and length increased rapidly until block 23, removed October 1, was completely riddled. The


N
SHELIKOF STRAIT
COOK INLET
KODIAK I.
AFOGNAK I.
KODIAK
KENAI PENINSULA
SEWARD
A-105
A-104
ALBATROSS BANK
MAP SHOWING LOCATION OF
TEST BOARDS
KODIAK I. AND KENAI PENINSULA
ALASKA 1923
NAUTICAL MILES
0 10 20 30 40 50

setacea, the
numbers ha
12 of *Bank*
the attack
blocks were
found, but
probable th
Bryozoa an

Tempera
vey as foll
board was

Year	M
1921....	Nov
	Dec
1922....	Jan
	Feb
	Mar
	Apri
	May
	June
	July
	Aug
	Sep
	Oct
	Nov
	Dec
1923....	Jan
	Feb
	Ma
	Apr
	Ma
	Jur
	Jul
	Au
	Sep
	Oct
	No

A-103–
1922, and
ruary 1,
setacea h
only 3/16
of both *1*
inch long
noria an
No assoc

A-101-
block 5,
board.
was so
worm p
blocks f
tained f
were fo
length o
rapidly

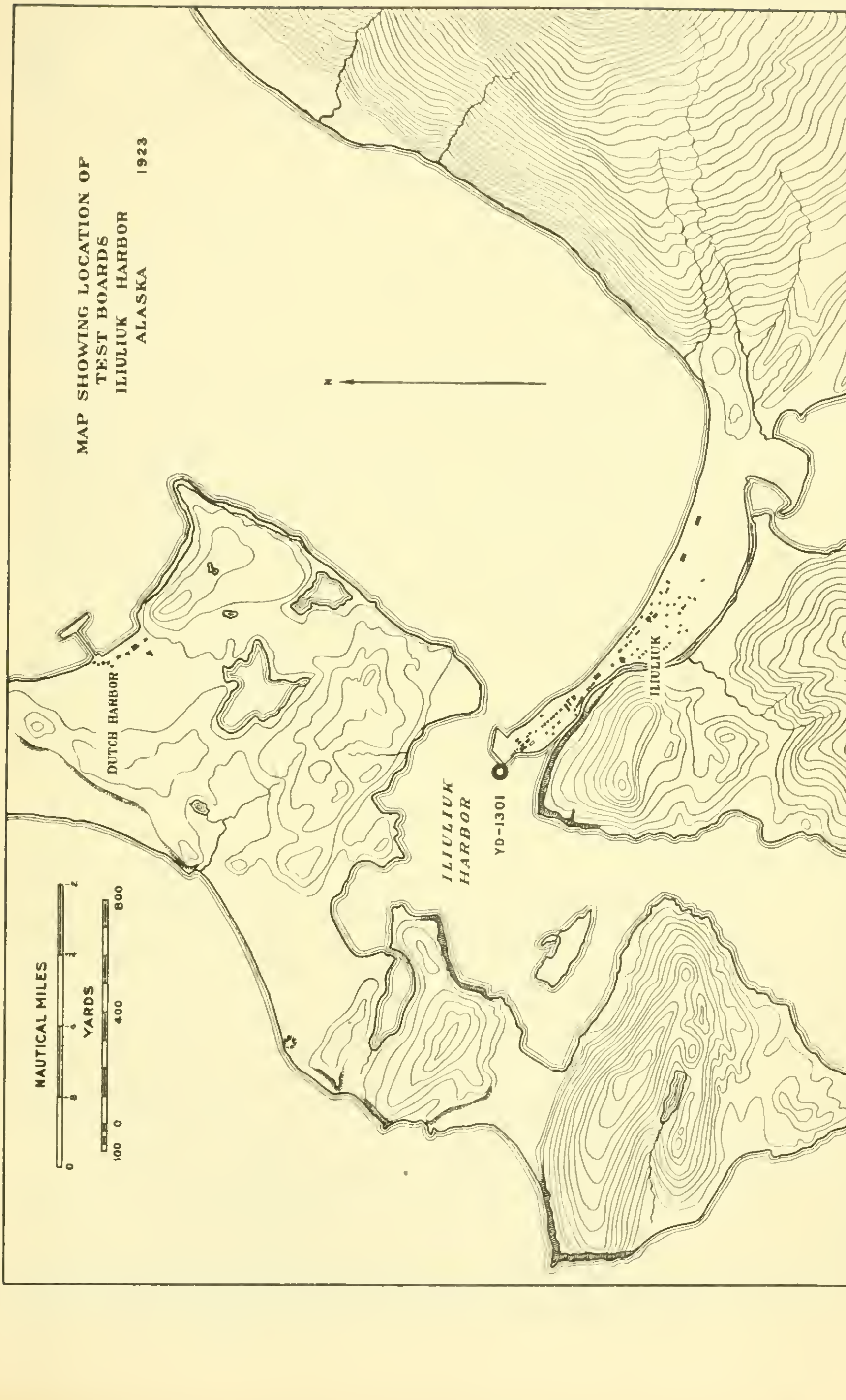

MAP SHOWING LOCATION OF
TEST BOARDS
ILIULIUK HARBOR
ALASKA
1923
N
DUTCH HARBOR
ILIULIUK HARBOR
YD-1301
ILIULIUK
NAUTICAL MILES
YARDS
100 0 400 800

FIG. 151.

largest animal that could be measured was about 12 inches long. The only associated organism was *Balanus*.

YD-1303—One hundred and twenty specimens of *Limnoria* appeared on the first block, removed May 1, and about 250 on the third, removed June 1, this number increasing gradually through the summer. Associated organisms were *Balanus*, Bryozoa (*Bugula*) hydroids, Amphipoda and *Membranipora*. *Bankia setacea* was not found in large numbers. The last block reported was removed January 1, 1924.

A-104—No borers appeared for two months after the immersion of the board, when 22 specimens of *Limnoria* were found on block 3, removed January 13. This number increased gradually until block 11, removed on May 14, 1923, showed about 600 of *Limnoria*. The first shipworms (50), *Bankia setacea*, the longest ¾ inch, appeared on block 7, removed March 15, while with block 11, removed May 14, the length had increased to 2½ inches and the number to 60. Destruction by both *Limnoria* and *Bankia* proceeded rapidly until block 17, removed September 21, was completely filled. Associated organisms were *Mytilus*, Bryozoa and hydroids.

A-105—Seven specimens of *Limnoria* were found on block 2, removed January 1, 1923, one month after the immersion of the board. This number increased until about 400 were found on block 11, removed May 16, 1923, and this number gradually increased. The first *Bankia setacea* was found in block 15, removed July 16, and while no large number of animals were found they had reached a length of 12 inches by September 16 and completely filled the block removed November 16. Encrusting Bryozoa and tube worms were the associated organisms.

YD-1301—No borers were found until block 6, removed March 16, 1923, three months after immersion of the board, when 16 specimens of *Limnoria* appeared. The number found on later blocks has increased, but no great number has been found on any block. No shipworms appeared prior to December 15. The associated organisms are Bryozoa, *Membranipora*, Algae, tube worms, *Amphipoda*, and on the June 1st block, a large number of minute specimens of *Balanus*.

Methods of Protection

Creosote Impregnation—There are a few structures along the coast built on creosoted douglas fir piles, but they have been constructed too recently to furnish reliable information as to the life to be expected from this method of protection, though the opinion of some wharf owners seems to indicate about 12 years.

Some native spruce piles were sent to Seattle by the Alaska Central Railroad in 1905 for creosoting, but the treating plant reported that the timber was badly injured by the treatment and the piles were not used. It seems probable that if industrial demands are sufficient, a method for creosoting the native timber can be developed.

Other Timbers than Spruce and Fir—Wharf owners in several harbors report that unbarked hemlock piles will last approximately three times as long as spruce, or as long as two to three years where the borer attack is heavy.

After the collapse of the Alaska Central Railroad dock at Seward in 1905, a portion of it was redriven with cottonwood piles. This dock was burned

about two or three years later, at which time no attack on the cottonwood was found.

The Alaska Packers' Association built a dock on spruce piles in about 1908 in Uyah Bay on the mainland across Shielkof Strait from Kodiak Island. This dock failed two or three years later on account of shipworm attack and because of the fact that cottonwood piles (which had been in place over 20 years) were still in good condition in another arm of the Bay, the dock was rebuilt, using cottonwood piles. This dock is still in service and reported to be in good condition.

Substitutes for Timber

There are no records available of structures of any importance built of concrete, iron or steel in Alaskan waters.

Conclusions

Attack by marine borers can be expected in practically all harbors south and east of the Aleutian Islands. Unprotected spruce and fir piles can be expected to last from six months to two years; unbarked winter cut hemlock may last two or three times as long as spruce.

The record of cottonwood piles is good and where this timber can be obtained it offers considerable promise as a wharf material.

It appears that *Limnoria* attacks throughout the year, but that its attack is heavier after April 1 than before that time.

Bankia setacea breeds in January and February, but it does not appear that many larvæ survive or that much growth takes place until about April 15. The rate of growth generally increases from that time until about June 15, when it reaches its maximum. Some variation is found in the different harbors, but not more than might be caused by local conditions surrounding the test boards.

GUANTANAMO, CUBA

Description

The Naval Station at Guantanamo (Fig. 152) is leased from the Cuban Government. The lease covers an area of about 47 square miles, of which 9,485 acres is water.

The climate is semi-arid, with an average temperature varying from 75° Fahr. in February to 85° Fahr. in August. The average range of tide is 1.35 feet, and the currents are inappreciable.

The wharves, of which there are seven, have depths of water alongside varying from 30 feet at the Main Station Wharf to 5 feet on the northwest side of the South Toro Cay Wharf. The anchorage has an area of about 8 square miles.

Marine Borers

Past History—Marine borers, both molluscan and crustacean, are known to be constantly present, and unprotected timber is never employed in structures exposed to sea water, except in the case of temporary construction.

Committee Investigations—Test boards were established at two locations as shown in table on page 414.

Blocks were forwarded for inspection at semi-monthly intervals. The results were as follows:

YD-C-1—Young shipworms were numerous on block 2, removed November 30, with tube lengths up to 8 mm. The number increased to about 100, and the maximum length to 25 mm. in block 3. The specimens contained in block 4, removed December 30, were of sufficient size and numbers for identification, and the following determinations were made:

Teredo (Lyrodus) sp. "G"
Teredo (Zopoteredo) johnsoni
Teredo (Teredo) portoricensis

to which were added from the later examinations:

Teredo atwoodi
Teredo (Teredo) sp. "E"
Teredo sp. "F"
Teredo sp. "Q"
Bankia sp. "V"

The majority of animals found in all blocks were of *Teredo sp. "G." Bankia sp. "V"* was observed only in block 4. The entire test specimen consisting of the supporting board, original blocks Nos. 9-24, and replacement blocks Nos. 25-31, was removed from the water March 15, 1923. An examination showed that unlike Northern localities, the shipworm embryos, particularly those of *Teredo (Lyrodus) sp. "G"* are in the water and are entering the wood as late as February 1. A diminished rate of growth, however, was observed in block 27, placed December 15, when compared with block 3, placed November 1 and removed December 15.

A new board of 1923 model was installed May 10, 1923, from which 5 series of blocks have been examined. As in the old test specimen, *Teredo sp. "G"* was always predominant, the resulting damage being severe and rapid. The maximum length of tubes noted was 130 mm.

Limnoria action of medium intensity occurred on all blocks, and a few specimens of *Martesia* were generally present. Associated organisms were *Balanus*, Bryozoa, Ostrea, and Anomia.

YD-C-2—These blocks yielded the same species found at YD-C-1, and an additional one, *Teredo clappi.* In all other respects they proved to be quite similar to those from YD-C-1.

Records of temperature and salinity observed at the site of both test specimens during the period November 16, 1922, to February 16, 1923, are shown on Figs. 153 and 154.

Test Boards, Guantanamo, Cuba

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
U. S. Naval Station, Guantanamo					
Main Station Pier	YD-C-1	Navy	Nov. 1, 1922	2.0	32.0
Fuel Oil Pier	YD-C-2	Navy	Nov. 1, 1922	1.5	18.5

Methods of Protection

Creosote Impregnation—At the U. S. Naval Station there are 5 waterfront structures supported by creosoted piles, all more or less affected by the attack of marine borers as shown in the following table:

STRUCTURE	BUILT	AFFECTED BY MARINE BORERS
Main Station Pier	1911-12; ⅓ rebuilt in 1919	Yes.
Fuel Oil Pier	1911	Yes.
Hicacal Beach Pier	Rebuilt 1920	Old piles—Yes. New piles—Slightly.
Ordnance Wharf.	1913	Yes.
Navy Wharf, Fisherman's Point	1905	Yes.

The first two structures, which are considered representative with respect to creosoted structures at this station, were treated under the following specifications:

> "The piles after being stripped of all bark, including as much of the inner bark as practicable, shall be subjected for five hours to the action of live steam under a pressure of not exceeding 20 pounds per square inch gauge. After the pressure treatment a vacuum of not less than 20 inches of mercury shall be created in the chamber containing the piles, which shall be maintained for six hours. Oil shall then be admitted to the chamber. The vacuum shall be maintained while the oil is flowing into the chamber and until the chamber is entirely filled with oil. Sufficient pressure shall then be applied to the contents of the chamber to force a penetration of oil not less than 1½ inches and a total absorption of not less than 16 pounds of oil per cubic foot of wood for long leaf pine and 18 pounds for short leaf or loblolly pine."
>
> "The oil used for the creosoting shall not flash below 185° Fahr. nor burn below 200° Fahr. The yield of naphthalene from the oil between the temperature of 410° and 470° Fahr. shall not be less than 42 per cent nor greater than 60 per cent by volume. Inspecting of the fender logs will be made at a point from which original shipment is made. Inspection of creosoting will be made at the creosote works."

The piles for both the Main Station and Fuel Oil piers were short leaf pine, the original number driven in the former being 534 and the latter 210. Approximately one-third of the Main Station pier piles was replaced in 1919 on account of the destructive action of marine borers. Of the original piles in the Fuel Oil pier 35 have been replaced subsequent to 1919, and many of those remaining are in need of replacement. The attack by both shipworms and crustacean borers is considered very serious, slightly more intensive on the Main Station pier than on the Fuel Oil pier. The range of destructive action is concentrated at the mud line and between low and high water.

Armor—The Lighthouse Wharf is built on treated piles protected by 12 inch diameter cast iron pipe which extends from below the mud line to above high water level. The date of construction is unknown, but was presumably prior to 1911. The present condition of the piles so protected is said to be good. The fender piles are creosoted and their condition is such as to require renewals.

Substitutes for Timber

Concrete—On account of the heavy attack of marine borers on the "Station Pier," the Navy, in 1922, constructed a new concrete pier 50 feet by 360 feet.

This pier is carried on reinforced concrete piles 15 inches square and from 65 to 80 feet long with four batter piles to each bent.

The reinforcement consisted of four one-inch corrugated square bars

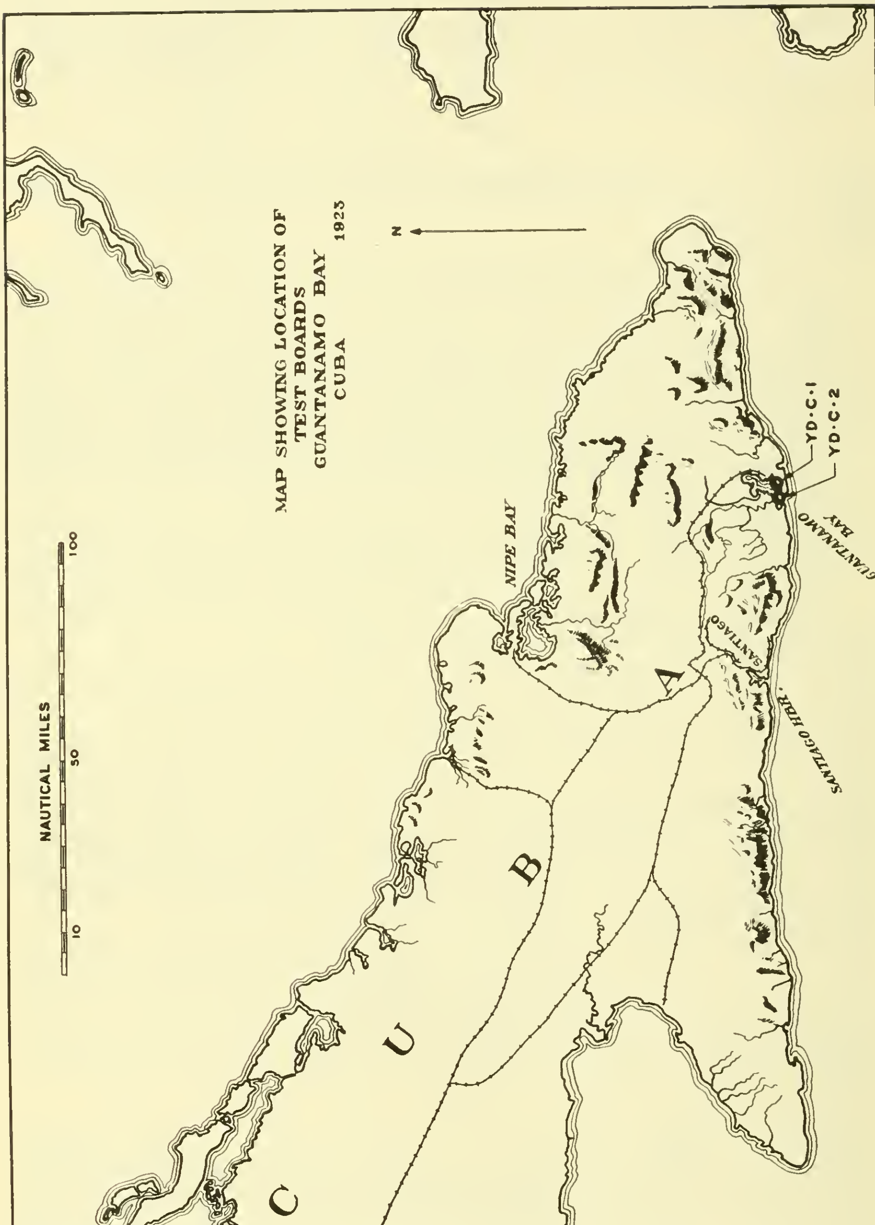

MAP SHOWING LOCATION OF
TEST BOARDS
GUANTANAMO BAY
CUBA
1923
N
NAUTICAL MILES
10
50
100
NIPE BAY
YD·C·1
YD·C·2
GUANTANAMO BAY
SANTIAGO
SANTIAGO HBR.
C
U
B
A

Fig. 152

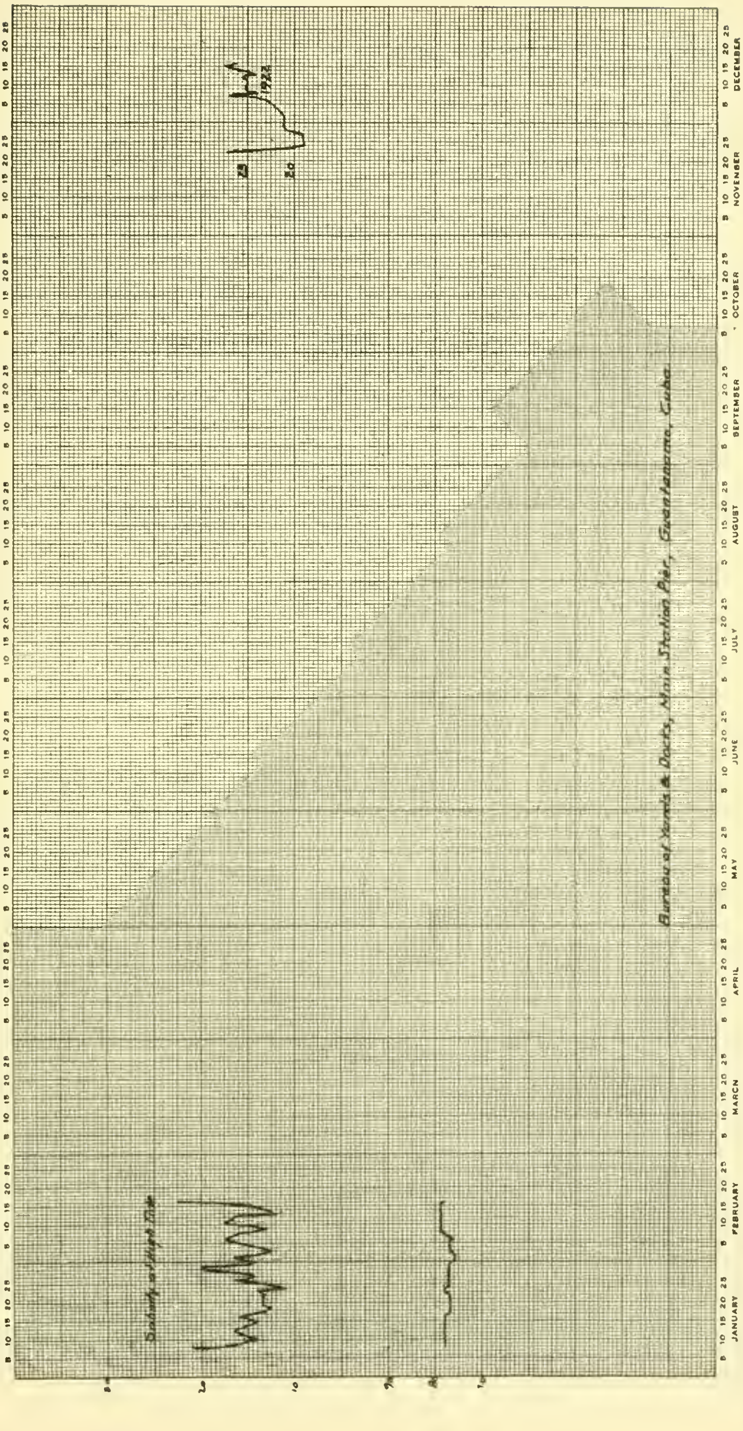


Fig. 153—Salinity and Temperature Observations, Main Station Pier, Guantanamo, Cuba

banded with 5/16 inch rods. The cover over the bars was only 1¼ inches, and over the bands only 15/16 inch, which the Bureau of Yards and Docks considers an experiment justified by the richness and density of the concrete.

The aggregates were local sand and gravel carefully screened and graded. The mixture was of "quaking consistency," in the proportion 1:1:2. The piles were cured from 35 to 72 days before driving, and were kept wet for the first 28 days of this period.

The reinforced concrete deck which is designed for a load of 500 pounds per square foot, or a 46,000 pound wheel load on the track, was built with the same materials and method. The mixture was 1:2:4 and of "quaking consistency," both the deck and the piles being carefully rammed and spaded.

This wharf was built by Yard forces and the piles are reported to have cost about $1.30 per foot or $1.70 per foot in place.

This structure is of course too new and too carefully built to show deterioration at the present time.

Conclusions

The attack of all types of borers is heavy, and though there appears to be periods when the activity of some species is lessened, there is a serious attack at all seasons of the year.

Well creosoted and undamaged piles may be expected to give an average life of about 8 years unless otherwise protected.

Cast iron pipe casings probably render the most efficient service for the protection of wooden piles.

VIRGIN ISLANDS

Description

The Virgin Islands lie wholly within the limits of strong northeast trade winds which, except when disturbed by atmospheric depression, blow with the greatest regularity during the entire year. The investigations covered the islands of St. Thomas and St. Croix, testboards having been located at St. Thomas and Christiansted respectively.

St. Thomas Harbor (Fig. 155), on the south coast of St. Thomas Island, is the most important harbor of the American group of the Virgin Islands. About 500 yards wide at the entrance between Rupert Rock Beacon and Frederick Point, it spreads out on either side into a basin about ¾ mile in diameter. The average temperature and salinity of the water are 82° Fahr. and 22 parts per thousand respectively. Although the water is apparently clean, a comparatively large amount of oil and waste is present and sewage from the city of St. Thomas (population in 1920, 7,747) is emptied, untreated, into the harbor. The maximum tide is approximately 1.3 feet, the average being slightly less than 1 foot. There are practically no currents except tidal variations of low velocity. The depth varies from a few inches along the beach, and 6, 8, or 10 feet along the piers to a maximum of 35 feet in the outer harbor. Hurricane season extends from July 15 to November 1, and during this period each year there are several storms in which the velocity of the wind reaches 75 miles per hour. The last severe hurricane occurred in 1916, the wind on that occasion exceeding a velocity of 100 miles per hour. Except under unusual conditions the wave height in the harbor, which is well protected, is negligible.

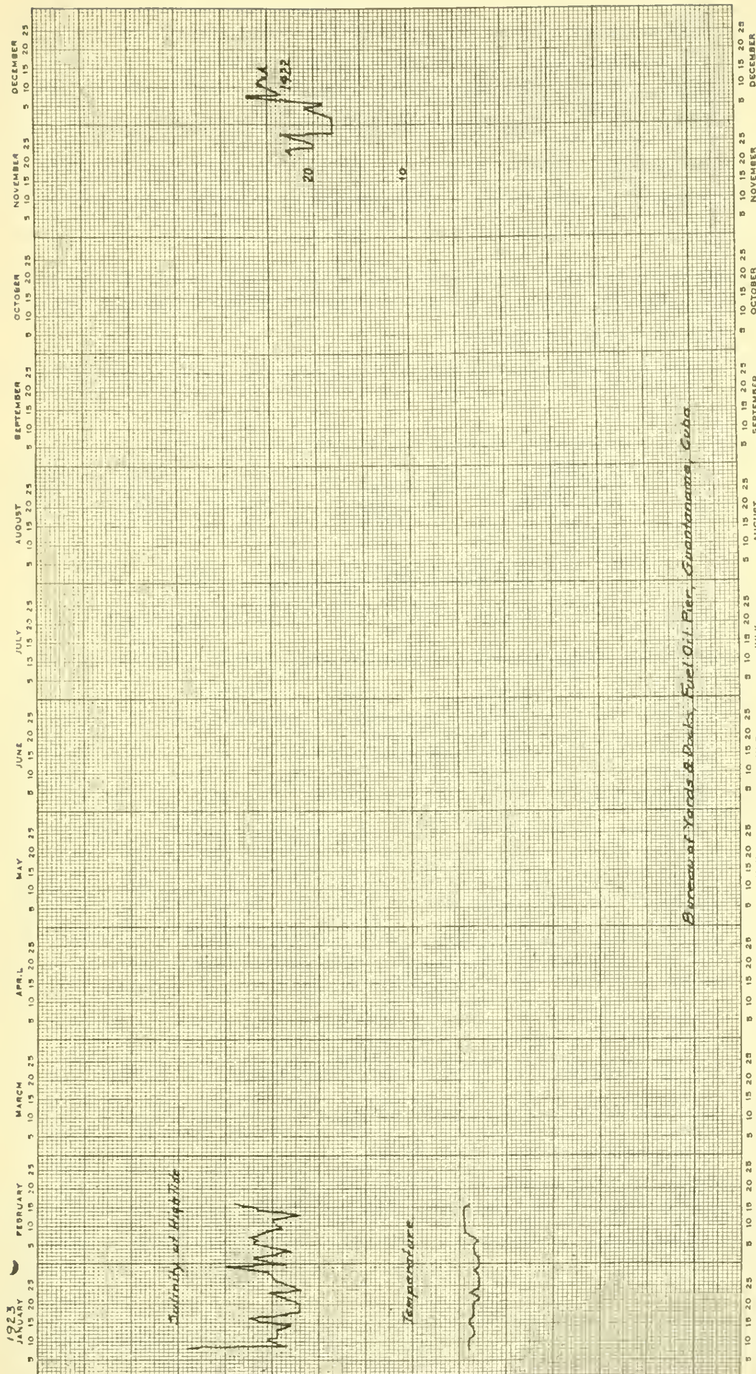


Fig. 154—Salinity and Temperature Observations, Fuel Oil Pier, Guantanamo, Cuba

Christiansted Harbor (Fig. 156), the greater part of which is shoal, is on the north coast of St. Croix Island and its principal entrance is by the channel between Long Reef and Scotch Bank, which has a charted least depth of 21 feet. Along the face of the town of Christiansted, south of Protestant Cay (a small islet in the harbor, 150 yards north of the town), there is a stone quay with 12 feet of water alongside, which is a loading pier for small vessels. There is also a small wharf at the Central Sugar Factory for unloading coal barges. The range of tide is about 1 foot.

Marine Borers

Past History—Until the beginning of these investigations there were few records concerning marine borers in these waters although they were known to exist in great numbers.

Committee Investigations—Standard test boards were installed as follows:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
St. Thomas Harbor Municipal Pier	YD-V-1	Navy	Sept. 1, 1922	2.0	9.5
Christiansted	YD-V-2	Navy	Sept. 15, 1922	0.3	8.5

The results of the examination of blocks from these test boards were as follows:

YD-V-1—Block 2, removed September 30, contained about 100 very young shipworms. The length of the tubes had increased to ½ inch in block 3, and in block 7, removed December 18, *Teredo sp. D* 3 inches in length was noted. The destruction, both rapid and severe, was due mainly to *Teredo sp. G* which formed about 95 per cent of the shipworms. Other species identified were *Teredo sp. J*, *Teredo johnsoni*, *Teredo sp. Q* and *Teredo portoricensis*. A new board of 1923 model was substituted for the old April 2. Shipworms appeared on the first blocks removed from this board and the attack became so severe that it was found impractical to continue the test due to the loss of the supporting board. *Limnoria* action was of medium intensity. Associated organisms were *Balanus*, Bryozoa, Ostrea and Algae.

YD-V-2—The first block to show shipworms was block 6, removed December 30, in which 1 specimen of *Teredo clappi*, 1 inch long, was found. Block 8, removed February 8, contained 3 specimens of *Teredo johnsoni*, the longest tube being 1 inch in length. Two specimens, one each of *Teredo atwoodi* and *Teredo clappi*, length 200 mm. and 18 mm. respectively, were found in blocks 9, 10 and 11. Block 12 contained no shipworms but was well scarred by *Limnoria*. Several hundred shipworms were found in block 13, removed April 16, the majority of them being *Teredo somersi* with lengths not exceeding 20 mm. The same block contained a few specimens of *Teredo clappi* 40 mm. in length. Blocks 14-20 inclusive contained from 20 to 50 specimens of *Teredo somersi* and *Teredo clappi* with lengths reaching up to 75 mm. and 90 mm. respectively. Block 23, removed September 17, was the last to be examined. This contained one specimen of *Teredo somersi* and one of *Teredo fulleri*. Embryos were found in the animals from

blocks 13, 17, 18 and 23, removed April 16, June 15, July 2 and September 17 respectively.

Field Tests—Test blocks bound with iron bands spaced at intervals of ¼ inch, from ½ to 2½ inches, were submerged at St. Thomas. A discussion of the results of this test will appear later.

Methods of Protection

With few exceptions, timber structures are confined to small and unimportant piers. The piles of these structures are usually brush coated with

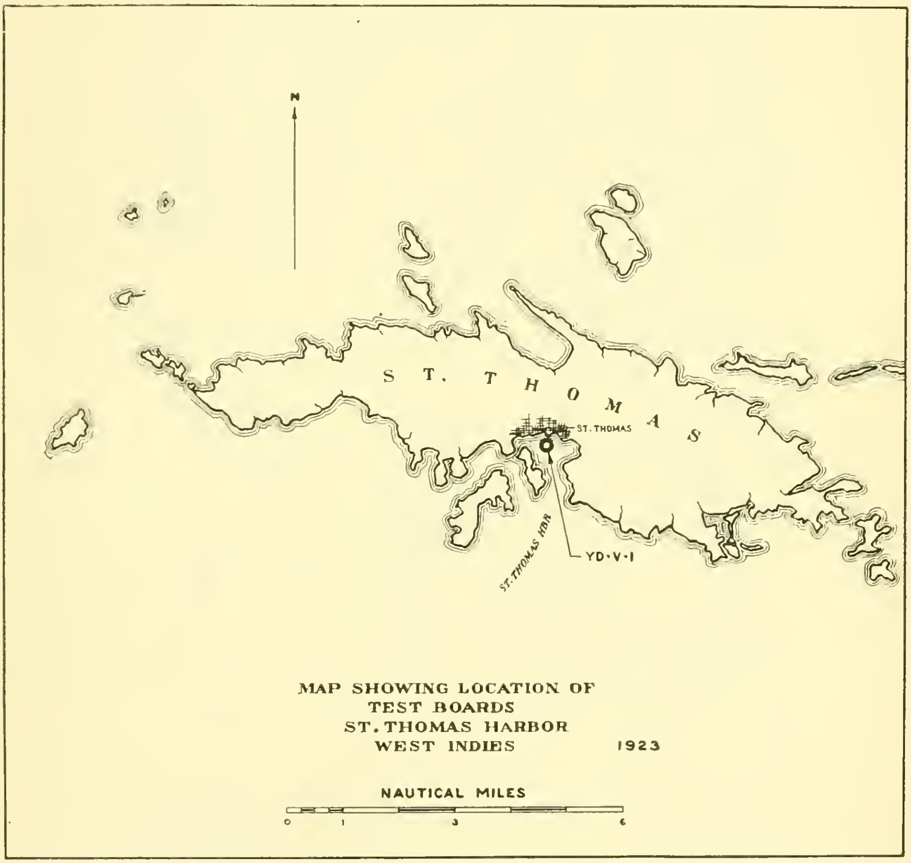


FIG. 155

pitch and tar and if of native timber they are often charred to a depth of about ½ inch. When carefully done, this treatment is said to prolong the life of piles beyond the year usually reckoned for untreated timber. Piles treated with 16 pounds of creosote per cubic foot and driven in 1918 in structure No. 1, Naval Wharf, St. Thomas, were removed in 1922, being practically destroyed by shipworms. (See page 127.)

Armor—In several cases in St. Thomas Harbor, including the large piles at the coal docks and the dolphins at the Municipal Piers, that portion

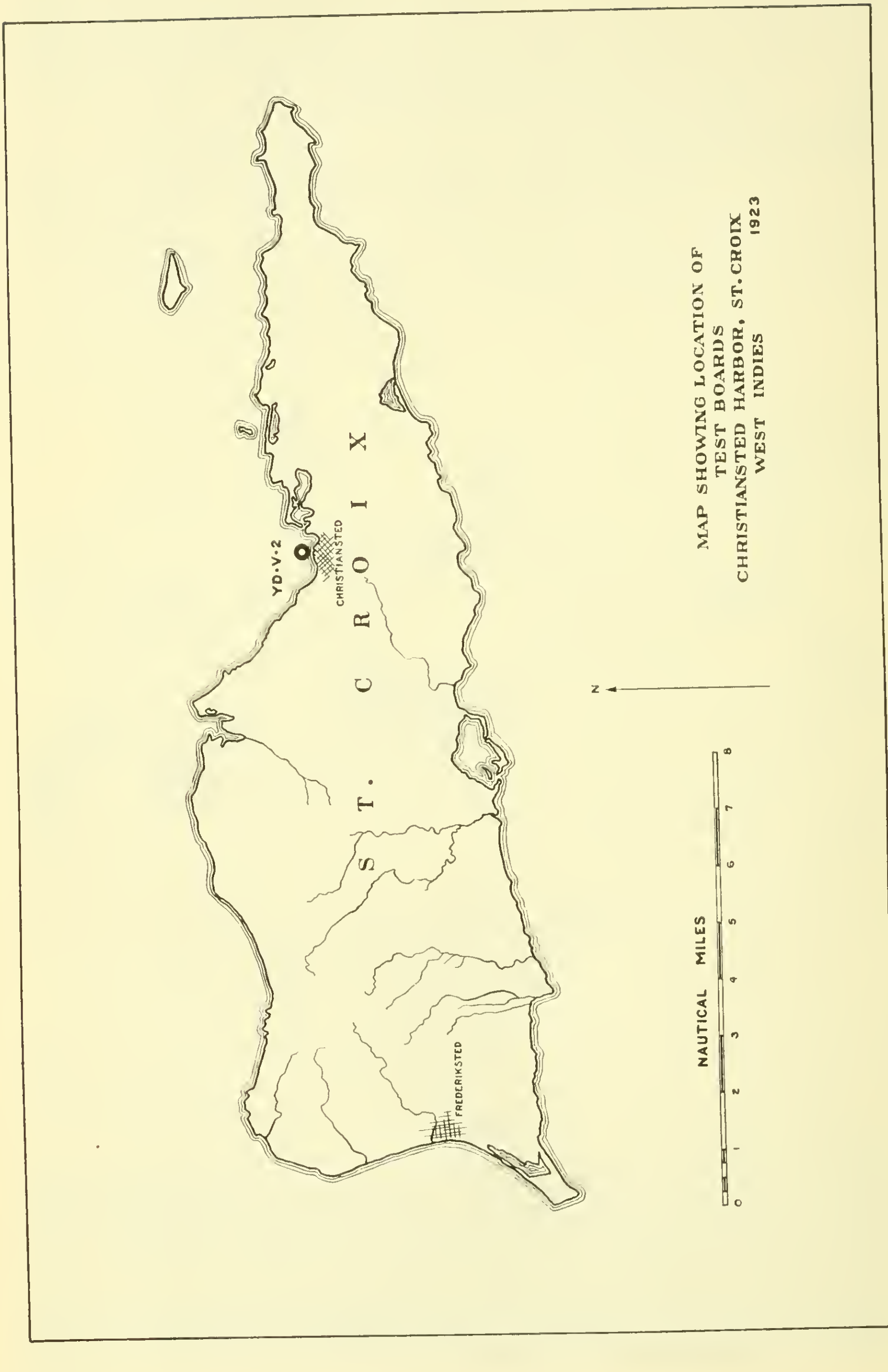

ST. CROIX
YD·V·2
CHRISTIANSTED
FREDERIKSTED
N
NAUTICAL MILES
0 1 2 3 4 5 6 7 8
MAP SHOWING LOCATION OF
TEST BOARDS
CHRISTIANSTED HARBOR, ST. CROIX
WEST INDIES 1923

Fig. 156

of the pile from the mud line to two feet above the water line is encased in copper sheathing, the pile having previously been covered with felt. This method of protection has been more satisfactory than any other in use and so long as the sheathing is kept absolutely intact no deterioration results. However, it has been noted that the smallest dislodgment of the sheathing allows the *Teredo* to begin its destructive work under the most favorable circumstances. Under such conditions the pile lasts only a short time, the copper shell alone remaining after a few months of the activities of the borers.

The oil pier of the West Indian Company, Limited, in the harbor of St. Thomas, consists of one hundred and twenty-five untreated yellow pine piles, eighty-one of which are used as dolphins and the remainder as bearing piles under the pier. The diameter of the piles varies from sixteen to twenty inches and the copper sheathing covers the whole length of the pile from the point to the butt. It is of No. 20 gage pure copper as it was found that composition sheets did not fulfill the requirements. Of the piles noted only three show any signs of deterioration after having been in place about eight years, and the sheathing of these three has been damaged by collision by vessels or flotsam. The remaining piles appear to be in practically as good condition as when they were driven and will probably last indefinitely if the copper casing is not damaged by exterior interference.

The small structures in which copper sheathing has been used, appear to be in practically the same condition as the West Indian Company's pier.

Substitutes for Timber

Metal—Steel and wrought iron piles and steel sheet piling have been used in a number of piers at St. Thomas. The deterioration of the iron and steel cylinders is of course somewhat less than that of wood piling, but in a number of cases the metal is badly rusted, between the high and low water lines, and in some instances, piles which have been in place for seven or eight years have been replaced or need replacement. Corrosion is present but no electrolytic action is discernible. The surface is badly rusted and pitted, the worst condition existing between the high and low water marks.

Concrete—There are no concrete structures of importance in either St. Thomas or Christiansted harbors for which records are available.

Conclusions

Both crustacean and molluscan borers are active in Virgin Islands harbors, and timber structures, unless protected with cast iron or copper armor, are of doubtful economy.

Metal structures of proper design, material and construction deserve consideration for this territory.

REPUBLIC OF HAITI

Marine Borers

Past History—It has not been possible to collect any records of value, though the rapid destruction caused by marine borers is well known.

Committee Investigations—Standard test boards were installed as follows (Fig. 157):

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Port au Prince	YD-P-1	Dept. of Public Works	Dec. 1, 1922	5.0	6.2
Aux Cayes	YD-P-2	Dept. of Public Works	Jan. 15, 1923	2.0	5.5

On account of the transportation service, blocks were received somewhat irregularly and were consequently not always in the most favorable condition for examination. The results follow:

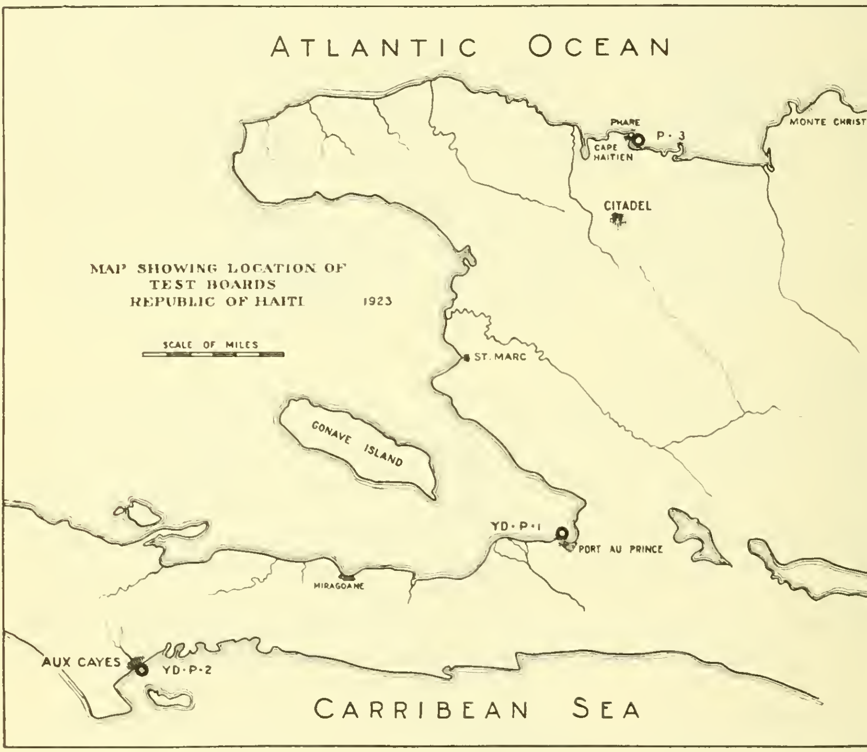


FIG. 157

YD-P-1—Many shipworm punctures were visible on block 1, removed December 15. Block 2 contained about 200 embryonic shipworms, and block 3, removed January 15, about 100 specimens of *Teredo portoricensis* and *Teredo sp. G,* the largest animal having attained a length of 30 mm. Block 4, removed February 1, was well filled with *Bankia sp. V, Teredo sp. E, Teredo portoricensis* and *Teredo sp. G,* the two last named having tubes of 30 mm. in length and containing larvæ. In block 5 the greatest length recorded was 3 inches; *Bankia sp. X* and *Teredo clappi* also appeared in this block. Succeeding blocks were well filled, the majority of specimens being *Teredo sp. G,* except in block 10. Block 10 contained *Teredo sp. W.* A new board of the 1923 model was substituted for the old, June 1. The

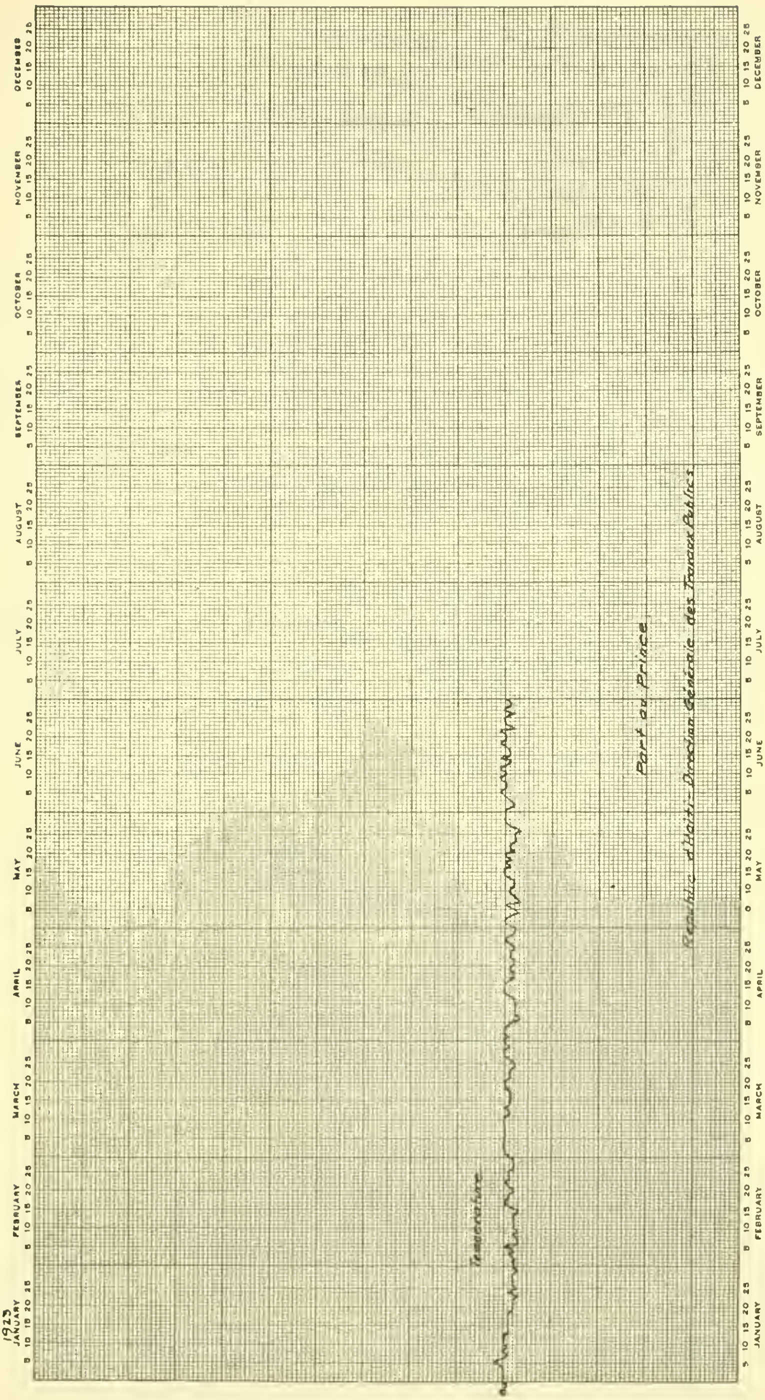


FIG. 158—TEMPERATURE OBSERVATIONS, PORT AU PRINCE, HAITI

new blocks were attacked with about the same degree of intensity as the old, the numerical supremacy shifting from *Teredo sp. G* to *Teredo clappi* and again to *Teredo sp. G*. *Teredo johnsoni*, *Teredo somersi* and *Teredo fulleri* were added to the list of new species. The largest specimen of *Teredo* found was 100 mm. in length, representing a growth of not more than 2 months; the largest of *Bankia* was 125 mm. in length, the age of the specimen not exceeding 4 months. *Limnoria* action was severe. Associated organisms were *Balanus* and Bryozoa.

Temperature records at this location will be found on Fig. 158.

YD-P-2—Shipworm embryos appeared on block 1, removed February 16. Block 2 contained about 100 specimens of *Teredo sp. G*, with lengths of tubes up to 5 mm. Block 3 and succeeding ones were well filled, the greatest lengths of tubes ranging from 30 mm. in block 3, to 60 mm. in block 4. A few specimens of *Teredo sp. Q* were noted in block 5. A new board of 1923 model was substituted June 1, the blocks of which showed attack of similar intensity to that occurring in the old test specimens. One month blocks showed a growth of 15 mm.; this was increased to 100 mm. in the 2 months block. The last blocks examined (series No. 4) were removed October 1.

Methods of Protection

No records have been obtained except those of a steamship dock at Port-au-Prince which was built in 1909-10, supported by "Ripley Composite Piles." These are timber piles protected by concrete casings heavily reinforced by heavy mesh. In 1923 the owners reported that this wharf was in good condition, but it does not appear that a careful inspection had been made.

DOMINICAN REPUBLIC, WEST INDIES

Description (Fig. 159)

San Pedro de Macoris, on the south coast of the Island of Haiti, is a land locked harbor with a depth in the channel and along the docks of about 15 feet. The only storms are cyclonic, which occur usually about once in three years during the months of August, September or October. During the storm of September 11, 1921, the wind from the north attained a maximum velocity of 75 miles per hour and the waves a height of about 4 feet. The temperature of the water, which is of full ocean salinity, averages about 78° Fahr. On account of the waste from molasses distilleries the water is never clear. The tides are very small, averaging about 1.18 feet. An occasional rise in the Higuamo River produces currents of low velocity in the harbor. The tidal currents are negligible.

Santo Domingo Harbor, on the south coast of the Island of Haiti and west of San Pedro de Macoris, consists of an Inner and Outer Harbor. During the rainy season, silt brought down by the Ozama River, is present; during the three winter months the water is clear, as there are no sewage, chemical or other wastes. The temperature of the water averages about 78° Fahr. The water of the Outer Harbor is of full ocean salinity; that of the Inner Harbor brackish. Normally the surface water of the Inner Harbor to a depth of 1½ feet is sufficiently fresh for use in boilers; during the flood stages of the river this depth is increased from 3 to 4 feet. The normal tidal range is about 1 foot. There is a minimum depth of 15 feet in the channel and along the docks. This harbor is subjected to storms of

similar frequency and intensity to those recorded for San Pedro de Macoris.

Puerto Plata Harbor is located on the north coast of the Island of Haiti, and has depths ranging from 3 feet at the shore line to 75 feet at the entrance. Around the wharf in the ship channel the depth is about 19 feet. The temperature of the water, which is of ocean salinity, averages about

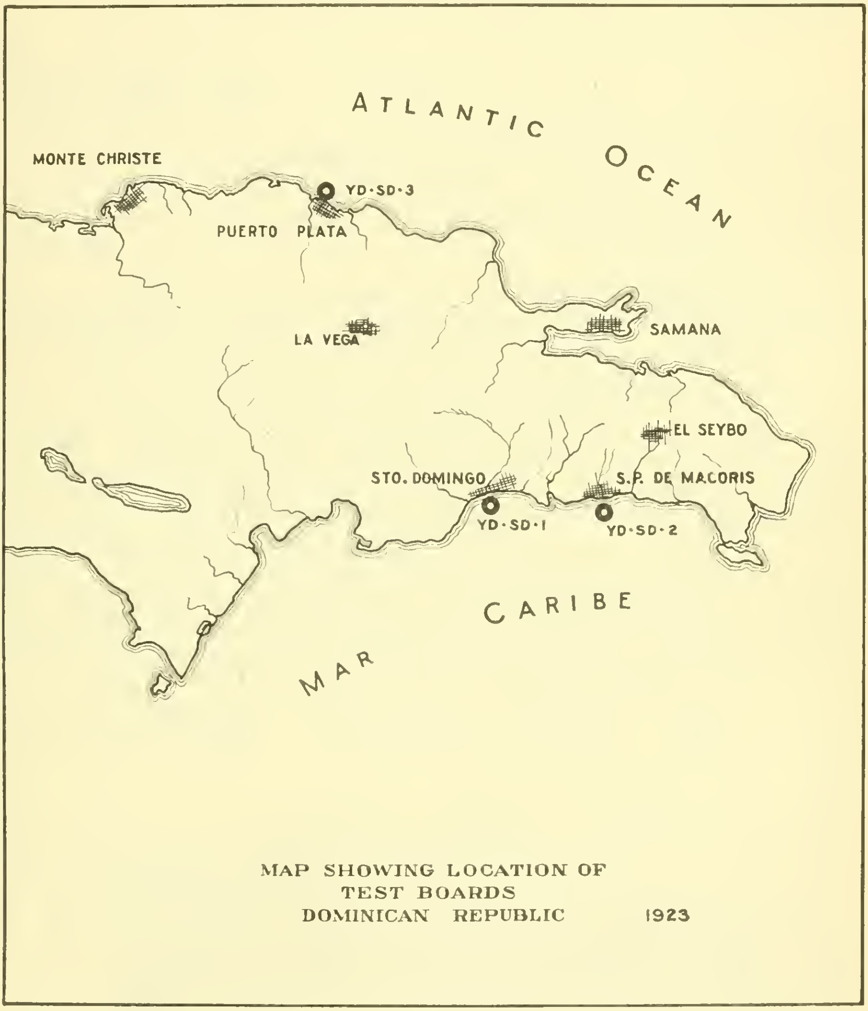


Fig. 159

78° Fahr. There is present a considerable amount of silt and refuse brought down by a small river and from the surface drainage of the city of Puerto Plata. The tides are fairly uniform, ranging from 3 to 4 feet, and small storms are frequent.

Marine Borers

Past History—Marine borers, both crustacean and molluscan, were

known to be present in all three of the harbors described above, and their activity was thought to be continuous throughout the year.

Committee Investigations—In cooperation with the Department of Public Works of the Dominican Republic, through the courtesy of its Director General, the Committee was enabled to establish standard test boards as shown below:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
San Pedro de Macoris..........	SD-1.....	Dept. of Public Works — Dominican Republic............	Dec. 1, 1922	6.5	6.1
Santo Domingo................	SD-2.....	"	Jan. 1, 1923	1.0	7.1
Puerto Plata..................	SD-3.....	"	Jan. 10, 1923	1.0	8.2

Blocks from these stations were received fairly regularly but often in such a dry condition, on account of the length of time in transit, that examination of them was difficult. The results to date are as follows:

SD-1—About 100 shipworm embryos appeared on block 1, removed December 16, none of them being completely embedded in the wood. Block 2 contained no shipworms; block 3, about 100 from 2 mm. to 3 mm. in length; block 4, 50 up to 25 mm. in length, and block 5 and succeeding ones were well filled with specimens. In block 5, removed February 15, the tubes had reached lengths up to 70 mm. The species identified were: *Teredo portoricensis, Teredo sp. G* (which formed in all blocks the majority of the specimens), *Teredo atwoodi, Teredo clappi, Teredo sp. F, Teredo somersi, Teredo dominicensis,* and *Bankia sp. V.* The destruction was so rapid that it became necessary on April 1 to attach the blocks to a new board of greater thickness. The last block examined was No. 18, removed August 31. Specimens in this block had tubes of about 100 mm. in length. Embryos were present in blocks 1, 3, 4, and probably later blocks. *Limnoria* action was slight. Associated organisms were *Balanus*, Bryozoa, and *Ostrea.*

SD-2—Block 2, removed February 1, contained many hundreds of shipworm embryos, practically all of which were *Teredo sp. Q.* One specimen of *Bankia sp. V* was found. In block 3 the majority of the organisms were *Bankia sp. V*, and this numerical supremacy was maintained in the succeeding blocks. Destruction, although severe, did not progress so rapidly as at SD-1. A new board of the 1923 model was substituted for the old one June 1. All the remaining original and replacement blocks were examined, and the end of the season of activity was determined as having occurred about April 1. With the exception of block 2, removed August 1, which contained a single specimen of *Bankia* of undetermined species, 20 mm. in length, all of the new blocks were free from shipworms. The last blocks examined (Series 4) were removed October 1. Associated organisms were *Balanus* and Bryozoa.

SD-3—Shipworm embryos appeared in block 2, removed February 10, and reached a growth in length of 20 mm. in block 6, removed April 15, the specimens up to this time averaging about 25 in number. Block 7 and succeeding ones were filled, and at the time of the removal of No. 13, July 31,

the animals were passing from the blocks into the supporting board. The majority of specimens found in block 4 were *Teredo sp. G;* in block 6, *Teredo atwoodi;* and in block 7, *Teredo dominicensis.* On account of conditions noted above, later blocks, although received with fair regularity, have not been thoroughly examined. A few specimens of *Teredo sp. Q* were also found. *Limnoria* attack was at times severe. Associated organisms were Bryozoa (*Lepralia* and *Bugula*) and *Ostrea.*

Methods of Protection

Creosote Impregnation—Of the three harbors investigated, two of them, Santo Domingo and Puerto Plata, have no timber structures exposed to the action of marine borers. At San Pedro de Macoris there is one wooden dock, 850 feet by 40 feet, supported by 4 rows of timber piles on 10 foot centers longitudinally. The piles are long leaf yellow pine. The original installation was of unknown treatment; the replacement piles were treated with 16 pounds of creosote per cubic foot. The heads of the piles and all timber joints were coppered and great care was otherwise taken in the erection of the structure. After 24 years' service 46 of the 286 creosoted piles were replaced, having been destroyed by shipworms and *Limnoria* which gained an entrance through cracks caused by the action of ships against the docks and in some cases through defective creosoting.

The fender system of the new wharf at Puerto Plata is of creosoted long leaf yellow pine piles, with treatment of 16 pounds per cubic foot. After 4 years' service these piles were relocated at which time many of them were found to have been damaged severely by the scraping against them of ships and to a lesser extent by marine borers.

In the Bay of Monte Christy, on the north coast of the island, there is a wharf supported by piles of Yarey palm from 12 to 14 feet in length. These piles, untreated, last about 10 years and are said to be unattacked by shipworms, the destruction mainly resulting from decay and erosion at the tide level.

Substitutes for Timber

Concrete—The Military Governor reports on concrete structures as follows:

San Pedro de Macoris

General Description of Structure and Conditions.

Type: Reinforced Concrete dock on precast piles.

Size: 660 feet long by 30 feet wide by 4 feet 6 inches above M. L. W.

Piles: 4 rows of piles 9 feet 8 inches c. to c. by 10 feet 10 inches c. to c. longitudinally. Heads of piles extend 9 inches into girders. 1 row 40 feet, 1 row 45 feet, 1 row 50 feet, and 1 row 55 feet long at each bent.

Girders: Transverse girders 3 feet 6 inches by 14 inches, and longitudinal girders 3 feet 5 inches by 14 inches on outside rows.

Deck: 12 inch slab 2-2-feet 6-inch gauge railroad tracks cast in deck, head of rail flush with top of deck.

Fender System: 12 inches by 12 inches creosoted yellow pine edge piece and string piece, fender piles creosoted yellow pine on 10-foot centers, 12 inches by 12 inches spacing piece at deck level between fender piles.

Moorings: Cast iron hollow bollards 50 c. to c. each side.

Lower 1 foot 6 inches of girders exposed to salt water by tidal action as bottom of girders is at approximately mean low water level. There is practically no wave or abrasive action.

Climate is hot during days and warm and moist nights with usually easterly trade winds during day.

PRECAST PILES.

(a) Type: Octagonal section, 14 inches in diameter. Piles cast in 1919, installed in 1920, except last 4 which were driven in 1921.

(b) Length exposed to salt water: 18 feet maximum, 6 feet minimum. Piles are immersed for their full length above mud line.

(c) Concrete materials: Large aggregate, corralline limestone, soft and porous from quarry at Km. 2 on Macoris Mato Mayor road. Crushed to ¾-inch size. Sand, river sand from Soco River, very fine, contained a few small shells and a small amount of coral.

Cement: Atlas Portland, standard test A. S. T. M.

Age: Not known.

Water: Brackish.

None of the aggregates were exposed to salt water before mixing.

(d) Reinforcement: Eight ¾-inch square deformed bars, with ¼-inch square bar spirally wound. The ¾-inch vertical bars extended out of the tops of the piles, a distance of 3 feet. These bars were bent after driving to conform to the reinforcement in the girders.

Type: Square Havemeyer bar.

Grade: Medium carbon steel, open hearth steel 33,000 pounds elastic limit. All bars were thoroughly cleaned before concreting.

Thickness of concrete cover: 1¾ inches.

(e) Concrete mix: 1:2:3, consistently wet enough to flow freely around reinforcement. Surface of piles appeared very dense.

(f) Curing: Piles were kept in forms a minimum of four days. Piles were cured for thirty days before using. They were kept wet for fifteen days. Water used for curing was brackish.

(g) Handling: Piles were moved after fifteen days to storage. Rolled on skids about six feet apart. When required for driving they were rolled on to three skids about 15 feet c. to c. and thence on to a low barge which supported the pile through two-thirds of its length. Piles were lifted off the barge with two lines at third points, a strain being kept on lower line until pile was nearly vertical. No hair line cracks noted.

(h) Driving: Hammer Arnot Steam No. 727. The heads of a few piles were spalled but not badly. This spalling is not a serious matter in this structure as heads of piles are cast 9 inches into girders.

(i) Present Conditions: As piles are submerged at all times, careful examination could not be made without a diver. However, no serious defects could be noted by feeling with the hands below the water level.

DECK AND SUPERSTRUCTURE.

(a) 14 inches x 3 feet 6 inches continuous girders over each bent and longitudinal on two outside rows.
Deck 12 inches thick, continuous.

(b) Exposures: Deck is 4 feet 6 inches above M.L.W.
Lower 1 foot 6 inches of girders is alternately exposed and wet as bottom of girders is approximately at mean low water level. Wave and spray action are not serious factors.

(c) Concrete materials: Same as in precast piles.

(d) Reinforcement in girders: 5¾ inch square deformed bars, 3 x 8 inch wire cloth on outside of bars on bottom and two sides, minimum cover of 2 inches. Steel same as in piles. There are three bars in bottom of beam and two at top. Center bar is bent over heads of piles to take diagonal shear.

Deck reinforcement: ½ inch square deformed bars running longitudinally on 9 inch centers, alternate bars bent up over transverse girders. Under bars, 3 inches x 8 inches Clinton wire cloth fastened to wire cloth from girders. Steel and cover the same.

(e) Mix 1:2:4. Wet enough to flow around reinforcement.

(f) Forms: Wood T. & G. lumber. Great difficulty was experienced with girder forms, and it was practically impossible to get them watertight, as bottom of form was in salt water and width of girder the same as pile. Placing was started when tide was lowest and the bottom third of girders filled first. Usually a day's run was three transverse girders with corresponding longitudinal girders. Construction joints were left at centers of outside girders. Diagonal joint was used (about 45° to horizontal). Lower foot and half of joint exposed to salt water.
No gunite was used on joints. Laitance was removed.
Deck was poured without difficulty, construction joint left center between bents.

(g) Curing: Lower part of girders in salt water continuously after pouring, amount wet depending on tides.
Deck was kept wet with water and covered with canvas for about two days after placing.

(h) Present Conditions: Immediately after stripping some of the girder forms it was found that the lower 6 inches contained practically no cement; the reinforcement was exposed in each case. These places were repaired by building a water-tight box around the lower part of the girder and after the defective concrete had been removed it was filled with fresh concrete rich in cement.
No overloading has been noted, although several fine cracks have appeared in the deck, which are probably due to shrinkage or improper curing.

Santo Domingo

General Description and Conditions.

There are three separate and distinct concrete structures in the inner harbor. None exist in the outer harbor.

Structure "A," located on west side of river, is a reinforced concrete quay 31 feet wide by 1,361 feet long and 4 feet above mean low tide, supported on precast concrete piles. Upper end about 3,000 feet above mouth of river.

Constructed in 1913.

Four piles each bent on 10-foot centers, bents 10 feet center to center. Reinforcing of piles carried into girders. One row piles 16 feet, two rows 30 feet, and one row 35 feet long each bent.

Girders: Transverse girders 12 inches x 26 inches deep. Outside longitudinal girder 10 inches x 26 inches deep. Two interior longitudinal girders 10 inches x 20 inches deep and two 8 inches x 16 inches deep, supporting 3 foot 6 inch gauge industrial railway track. Lower edge girders at mean high water level.

Deck: Originally constructed with creosoted yellow pine deck on 8 inch x 12 inch stringers. Wood deck at upper end of wharf replaced for 230 feet of length in 1920, with 9 inch reinforced concrete slab.

Fender System: 3 pieces 8 inches x 12 inches creosoted yellow pine with spacers between. Lower fender attached to piles.

Structure "B," located on west side of river, is reinforced concrete quay wall, 6 feet wide, 420 feet long and 5 feet deep, of solid concrete set on precast concrete piles with reinforced concrete ties extending shoreward. This structure joins to lower end of structure "A."

Deck: 4 feet above mean low tide. Constructed in 1913.

Piles: Precast octagonal, 14 inches in diameter, extending 4 feet into bulkhead; set in two longitudinal rows 3 feet 4 inches cc. Outer row 2 feet cc., inner row 3 feet cc.; piles 40 feet long.

Ties: Reinforced 1 foot 9 inches x 2 feet in cross section, extending back 54 feet from face of bulkhead to a mass of concrete 4 feet x 5 feet x 2 feet

deep, enclosing heads of three concrete piles 20 feet long. Ties spaced 21 feet cc.

Filling: Space back of wall filled flush with top of wall with ashes, earth, rock, etc., retained below water line in front by large broken coral rock, placed against inside face of piles.

Structure "C," located on east side of river, is a reinforced concrete quay wall of same type as "B," but using Chenoweth piles. It is located at mouth of river and acts also as a breakwater. It is 780 feet in length, the outer end turns back shoreward at an angle of 45° till it meets the beach, a distance of 150 feet. Deck 4 feet above mean low tide.

Practically no wave or abrasive action on structures "A" and "B" and for about three-quarters of the length of "C." Outer end of "C," however, is subjected to wave action and is constantly covered with spray. Climate hot during the day but cool and moist at night. Southeasterly trade winds prevail during day with land breezes at night.

PRECAST PILES.

(a) Type: There are two types of precast concrete piles used.

1. Octagonal, 14 inches in diameter, ranging in length from 16 feet to 40 feet; driven in place between Aug. 15, 1912, and Jan. 31, 1913; used in structures "A" and "B."

2. Chenoweth type, 14 inches in diameter; other data unknown; used in structure "C."

(b) Exposed length varies. Maximum of about 16 feet, with average of about 14 feet on outside piles, in structures "A" and "B." Same for structure "C," except at outer end, where maximum exposure is about 8 feet. Exposure between mean low and mean high water of about one foot. No exposure above mean high water, due to fact that heads of piles extend into concrete girders and bulkhead, which are placed with lower edge at mean high water.

(c) Materials: Aggregate, broken coral rock and river sand from Isabella River. Aggregate free from salt and not exposed to salt water before used. Sharp sand well graded from small to fairly large grains, contains small amount of salt. Mixing water from nearby springs, slightly brackish. Brand and quality of cement unknown.

(d) Reinforcement: Octagonal piles eight ¾-inch bars; other data unknown.
Chenoweth piles, no existing data, this work having been done by contract in 1910. Probably standard for this class of piles.

(e) Concrete mix: Unknown.

(f) Curing: Octagonal pile, Structure "A," maximum age 155 days, minimum (two only) 33 days; average 67 days.
Octagonal piles, structure "B," maximum age 67 days, minimum (two only) 10 days; average age 26 days.
Chenoweth piles, structure "C," no data.
No other data on curing.

(g) Handling: No data other than in (f), 0.5 per cent of piles broken by handling in structures "A" and "B."

(h) Driving: Structure "A," both steam and drop hammer.
Weight of hammers, steam 5600 pounds, drop 4800 pounds; average number of blows per pile, steam 391, drop 22.
Structure "B," drop hammer used, weight 4800 pounds; average blows per pile 48. 1.8 per cent of piles broken during driving in both structures. Structure "C," Chenoweth piles, no data.

(i) Present condition: Octagonal piles: Concrete appears to be in very good condition near water line and above, though it is badly spalled and broken in two or three cases, and reinforcing exposed. This at points where heads of piles are embedded in girders, structure "A," and caused from shocks when quay has been rammed by ships, or piles settling. Piling on outer line has settled about 8 inches in two places on structure "A." Settled at one place, structure "B," for a distance

of about 50 feet, maximum settlement 1 foot. Settled one place, structure "C," for a distance of about 35 feet, maximum settlement 1 foot. Condition of piling at point of settlement not inspected below water line, hence condition not known. At other points along dock where there has been occasion for divers to work, they have reported piles in good condition. Wire mesh reinforcing of Chenoweth piles exposed in many places, but considering length of service (12 years) piles are in remarkably good condition. Reinforcing rusted but very little.

DECKS AND SUPERSTRUCTURES; GIRDERS, ARCHES, BEAMS, SLABS, WALLS.

(a) Reinforced girders of varying sizes, see above.

(b) Exposure: Mean high tide level with bottom largest girders.
Practically no wave action or spray.
In structure "C" outer end constantly exposed to wave action, average wave height at this point being about two feet.

(c) Materials: See precast piles.

(d) Reinforcement: Quay section; structure "A"; girders (three 1-inch square bars in bottom of outside longitudinal girders, one bent up over heads of piles, six ½ inch stirrups; four 1-inch square bars in bottom of transverse girders, two bent up over heads of piles, six ½-inch stirrups). Three 1-inch bars bottom interior girder, two bent up over piles, four ½-inch stirrups. Bars supposed to be from 1½ inches to 2 inches from the face of concrete. In some cases bars touched forms and are now exposed.
Quay wall section, Structure "B."—Six 1-inch bars exterior face and six 1-inch bars interior face longitudinal, ½-inch ties, four 1½-inch longitudinal bars in back ties running to piles on shore. Other data unknown.
Quay wall section, structure "C," no data.
Deck Slab: 9 inches concrete, placed in 1920; ½-inch square rods 5 inches cc., placed longitudinally and bent up over beams.
Wire cloth mesh, 3 inches x 8 inches of No. 8 and No. 10 galvanized wire, also used.
All reinforcing bars 2 inches from face of concrete. Wire cloth 1 inch from face of slab.

(e) Mix: In girders, unknown. Bulkhead, 1:3:5, structure "B."
Structure "C," unknown. Deck slab, unknown.

(f) Forms: Wood; other data unknown.

(g) Curing: Unknown.

(h) Present Condition: Structure "A," deck slab appears to be in very good condition, considering class of workmanship and materials available. A few cracks have appeared, but they are probably due largely to settlement. Construction joints are tight. No spalling or pitting of concrete due to weathering noticeable. However, the concrete has been in place only since 1920-1921, and it is yet too early to form an opinion of the effects of weathering.
Only the outside longitudinal girders have been inspected for this report. In four places the girder is badly broken, the concrete having fallen away in quite large pieces, exposing the reinforcement, which is badly rusted. These failures are due to shocks received when quay has been rammed by steamers. There are also many places along the lower side of the girders, where concrete has been sheared off up to the reinforcing bars, leaving the steel exposed. In all cases the steel is badly rusted. These failures are due to the bending of the lower timber fender, when ships are being warped to berth. The upper edge of fender in most cases comes about 2 inches above lower edge of girder, thereby causing concrete to shear off when fender is bent. This is merely a matter of design and may be corrected by raising or lowering fenders.
There are a number of places where reinforcing has not been properly embedded, the result being rusting of same and spalling of concrete. This is especially true of the stirrups, nearly all of which are exposed, are now rusted away and useless. The concrete in girders appears to

be as dense as it is possible to obtain with aggregate used. Little weathering, even at the water line, is noticeable, other than that due to spalling of concrete due to improper placement of steel. All defects observed can be remedied in future structures by a few changes in design and more thorough inspection during construction.

Structure "B." This structure presents two failures. For about 50 feet of length, near the centers, the bulkhead has settled one foot. Condition of piling underneath unknown. Large cracks have appeared at center and ends of section failed. The other failure is at end of pier, where it was heavily rammed by a naval barge. Section of wall, about 20 feet long, broken off and separated from main structure by crack of about an inch. The concrete appears to be of good quality, considering material used. Little spalling noticeable except where reinforcement, in a few cases, has been placed too close to face of structure. Top of wall apparently covered after construction with an inch layer of mortar. This has weathered badly and come off in large pieces.

Structure "C." This is the oldest structure in the harbor, having been built in 1910 by a firm of American contractors. It is also the most exposed to action by the elements and is in the poorest condition as far as general appearance is concerned. There is one failure due to settlement of piling, but the remainder of the structure appears to be sound. As before mentioned, the outer end is subjected to almost constant wave action, waves at times being 5 feet in height, but there is no visible failure at this point, and the concrete appears to be in fairly good condition. There is a good deal of spalling of concrete, with consequent exposure of reinforcing. In every case this is due to improper placement of the reinforcing, the embedment at time of construction not having over ½ inch at these points. The concrete, too, appears to be greatly inferior to that in structures "A" and "B." Chipping and spalling of mortar placed on top of wall has occurred in same manner as in structure "B."

Puerto Plata

The new wharf is all concrete construction resting on concrete piles. It was built in 1917-18 by the Leonard Construction Company under contract. The floor being only 6 feet above mean tide, the under parts especially are exposed to wave and mist action.

Precast Piles.

(a) Piles used were of 14-inch octagonal section.

(b) Length of pile exposed to salt water is 20 feet, between low and high water is 3 to 4 feet and above high water 5 feet.

(c) Concrete materials were cement, screenings and broken limestone gauged with fresh water. Cement was standard American Portland Cement.

(d) Reinforcement was eight ¾-inch twisted bars and ¼-inch rod spirally wound with a 9-inch pitch.

(e) Concrete mixture was in the proportion of 1:2:3.

(f) Piles were cured forty days before moving.

(g) Driven by steam hammer and jet.

(h) Present condition of piles between low water and top of piles shows checks and cracks due to expansion of reinforcement, outer surface of piles is stained with oxides from the steel. On many piles large chips have been broken off due to this cause.

Poured in Place Cylinders.

(a) The old wharf rests on cylinders, poured in place.
Steel cylinders ½-inch thick, 4 feet in diameter.
Placed about the year 1895. No data as to construction methods.

(b) Exposure of 6 feet above low water.

(c) Present condition shows steel cylinders practically rusted away above low water with little apparent damage to concrete filling.

DECK AND SUPERSTRUCTURE.

(a) On the new wharf the concrete piles are capped with reinforced concrete beams which support a floor slab.

(b) Floor is 6 feet above mean tide.

(c) Concrete materials: Cement, sand, and broken stone, in the proportion 1:2:4.

(d) Beams reinforced with five ¾-inch twisted bars and ½-inch stirrups; floor 10½ inches thick and reinforced with ⅝-inch twisted bars spaced 6 inches, transverse rods of ⅜-inch twisted steel spaced 18 inches.

(e) A 1:2:4 mixture was used.

(f) Forms were of wood and watertight.

(g) Forms were kept in place seven days.

(h) Beams and floor slabs have suffered no damage other than slight cracks at junction of pile and beams.

Conclusions

Shipworm attack in all harbors is heavy and all piles should be protected. While the test blocks do not show a continuous attack throughout the year of any one species, there are so many species present with an apparent difference in their period of activity that the attack may be considered of uniform intensity throughout the year.

The concrete structures reported are generally not old enough to show much deterioration, but they do contain lessons for the designer and the contractor.

PORTO RICO

General Description

Porto Rico lies within the limits of strong northeast trades, which when not disturbed by atmospheric depression, blow with great regularity during the entire year, varying in direction between northeast and southeast. There are occasional heavy gales during the hurricane season, July to October. The mean monthly temperature at San Juan varies from 75° to 81.3° Fahr. in February and August respectively. The water at San Juan is of full ocean salinity and temperatures recorded by the Corps of Engineers, U. S. A., ranged from 77° to 85° Fahr. in March and July, 1923, respectively. In general there is a narrow bank of soundings close to the island from the edge of which the bottom pitches off rapidly to great depths.

San Juan harbor (Fig. 160), 30 miles west of Cape San Juan, is about 3 miles long in a southeasterly direction, by from ¾ to 1¼ miles wide, the southwestern portion being occupied by extensive shoals. The northern side of the harbor is formed by San Juan Island, on the southern slope of which is situated the city of San Juan. The channel at the entrance has a depth of 35 feet and a width of about 250 yards; along the southwest front of the city the depth is 30 feet or more and the width about 150 yards and along the southeast part the width is about 350 yards and the depths vary from 22 to 32 feet. The range of tide is about 1.1 feet.

Port Arecibo (Fig. 161), 33 miles west of San Juan harbor, is an open bight formed by a recession of the coast about ½ mile on the west side of Point Morrillos, and into the eastern end of which flows the Arecibo River with a depth of 3 feet over the bar.

Mayaguez Bay (Fig. 162), on the west coast of the island, lies between Point Algarrobo on the north and Point Guanajibo on the south, a distance of about 3¾ miles and is about 2 miles in greatest length inside the shoals

which extend across the mouth of the bay. Two channels lead into the bay; the principal one entering between Inner Manchas and Manchas Grande shoals has a width of 3/8 mile and a depth of from 48 to 60 feet; the other leads into the bay from the northward and has a least width of 1 mile and depths of 18 feet or more. The tidal currents at the entrance have an estimated velocity of about 1 mile at strength. The Custom House landing at the city of Mayaguez has depths of 3 to 4 feet at its end.

Ponce Harbor (Fig. 163), on the south coast, is the eastern portion of an open bay 3 miles wide between Point Carenero on the east and Point

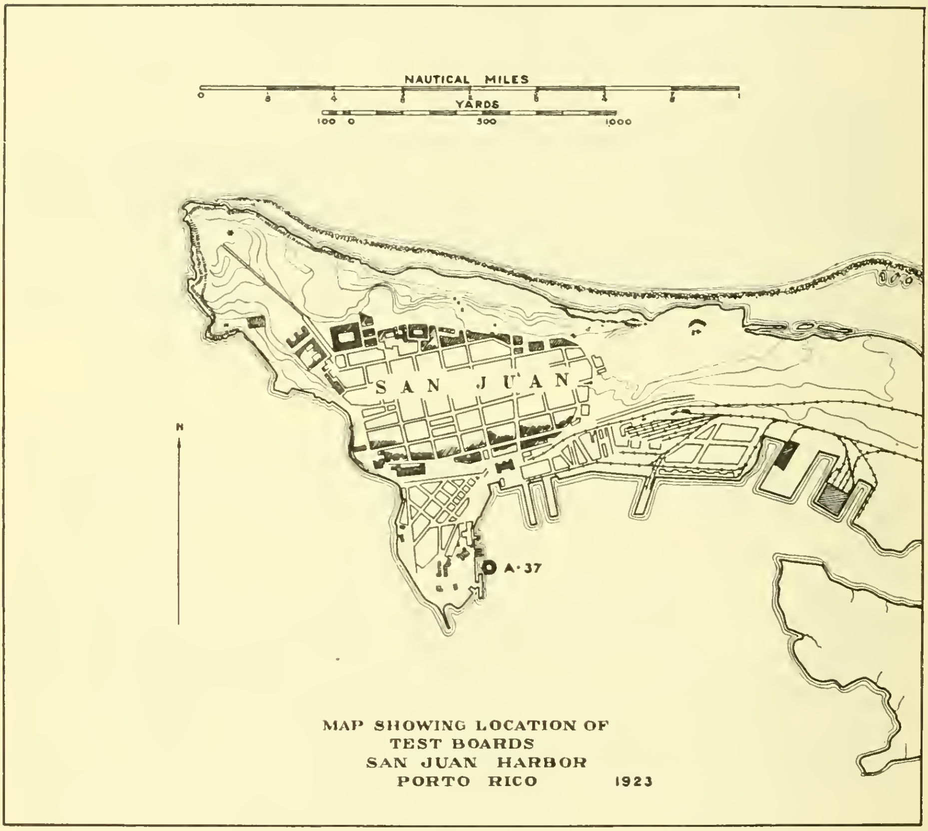


FIG. 160

Cuchara on the west. The harbor is about 1 mile long and 5/8 mile wide with depths of about 8 fathoms at the southern end, decreasing gradually towards the northern shore. Port Ponce is on the northeast side of the harbor and has several small lighterage piers. The municipal pier, at which there is a depth of 25 feet at mean low water, is located at Point Penoncillo.

Fajardo Harbor (Fig. 164), on the east coast, is about 3 miles south of Cape San Juan. The harbor is about 1/2 mile in diameter.

Marine Borers

Past History—Both molluscan and crustacean borers are present in

Porto Rican waters and, on account of the slight variation in temperature (75° to 90° Fahr.), were thought to be active throughout the year. The U. S. Army Engineers estimate the life of untreated timber to be from 1½ to 2 years.

Committee Investigations—Standard test boards installed were:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
San Juan	A-37	Army	Oct. 21, 1922	0.0	10.0
Arecibo	L-9-1	Lighthouse Service	Dec. 23, 1922	......	......
Mayaguez	L-9-2	Lighthouse Service	Dec. 4, 1922	......	......
Ponce	L-9-3	Lighthouse Service	Dec. 3, 1922	......	......
Fajardo	L-9-4	Lighthouse Service	Dec. 4, 1922	......	......

The inspection of the test blocks gave the following information:

A-37—About 50 shipworms, too young to identify, were found in the first block from this board—removed November 15. This number increased rapidly, the second block containing 100, the third 200 more or less and the fourth and succeeding blocks being well filled with specimens. The species identified were *Teredo sps. D, F, G, Teredo portoricensis, Teredo sp. Q, Teredo johnsoni* and *Bankia sp. V.* A new board (1923 model), was installed March 10, 1923, and the old test specimen was gone over in detail with the object in view of determining the end of the season of activity. There was found to have occurred no trace of a dormant period, during which attempts at boring by *Teredo* ceased—a condition differing radically from that in other Atlantic and Gulf waters where a distinct season of inactivity has been determined. It was established that the larvæ of *Teredo sp. G, Teredo portoricensis* and *Teredo johnsoni* were active as late as the latter part of February; those of *Teredo sp. D* the first of February, and those of *Bankia sp. V* and *Teredo sp. Q* as late as December 1.

A few shipworm embryos appeared on block 1 of the new board, removed April 5, the number increasing rapidly in succeeding blocks.

Limnoria action on some of the blocks was severe. Specimens of *Martesia* were at times numerous. The associated organisms were Bryozoa, *Balanus, Ostrea* and Algae.

L-9-1—The first shipworm (*Teredo sp. G*) appeared on block 4, removed February 23. Block 6, removed March 23, contained about 50 specimens; blocks 7, 9 and 10 were free from life of any kind; blocks 8, 11 and 12, a few dead specimens, and block 13 and succeeding blocks were completely filled with specimens of *Teredo sp. G,* the longest tubes noted being 75 to 100 mm. The last block examined was removed October 8. Aside from a few calcareous worm tubes, no evidence of other organisms was noted.

L-9-2—One specimen of *Teredo sp. G* was found on block 2, removed January 15, 1923. The number increased to 50 in block 3 (the longest tubes being 50 mm.), and succeeding blocks contained from one to several hundred specimens, ranging in length from 75 mm. (block 4) to 150 mm. (block 19). With the exception of occasional specimens of *Bankia sp. V* all shipworms examined were *Teredo sp. G.* Associated organisms were *Balanus,* Bryozoa (*Bugula* and *Lepralia*), and *Ostrea.* From 20 to 100 specimens of *Martesia* appeared on some of the blocks.

L-9-3—Block 2 was the only one received from this board. This contained a few shipworm embryos, two of which were examined. These proved to be *Teredo sp. G.*

L-9-4—Block 2, removed February 16, contained 3 specimens of *Teredo sp. G,* 8 mm. in length. Block 3, removed two weeks later, was well filled

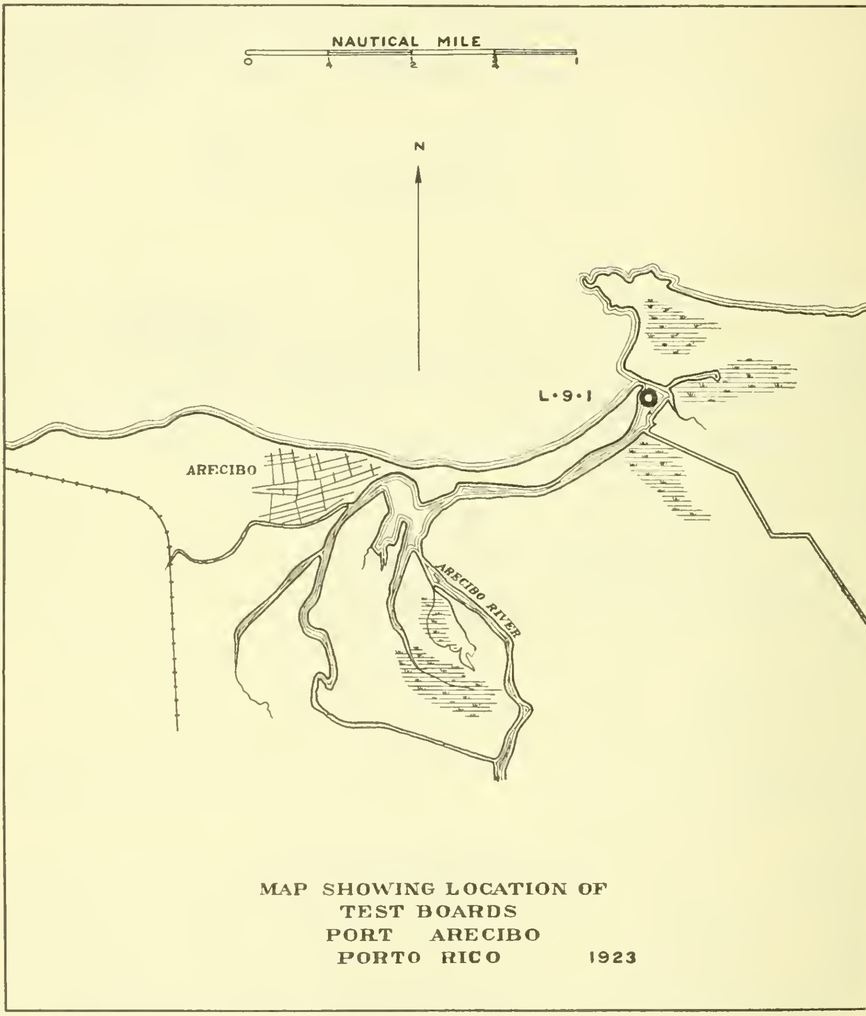


FIG. 161

with shipworms, the majority being *Teredo sp. G* of 50 mm. in length. Other species identified were *Teredo sp. Q, Teredo portoricensis, Teredo johnsoni, Teredo clappi, Teredo sp. D* and *Teredo sp. F.* The succeeding blocks were all well filled with shipworms, those of *Teredo sp. G* continuing to greatly outnumber other species till block 12 was reached. In blocks 12 to 24 (removed September 17 and the last one examined) speci-

mens of *Teredo clappi* were far more numerous than those of the other species. *Limnoria* action was severe at times. Associated organisms were Bryozoa and *Balanus*.

In addition to the regular block inspection, a section of a creosoted pile

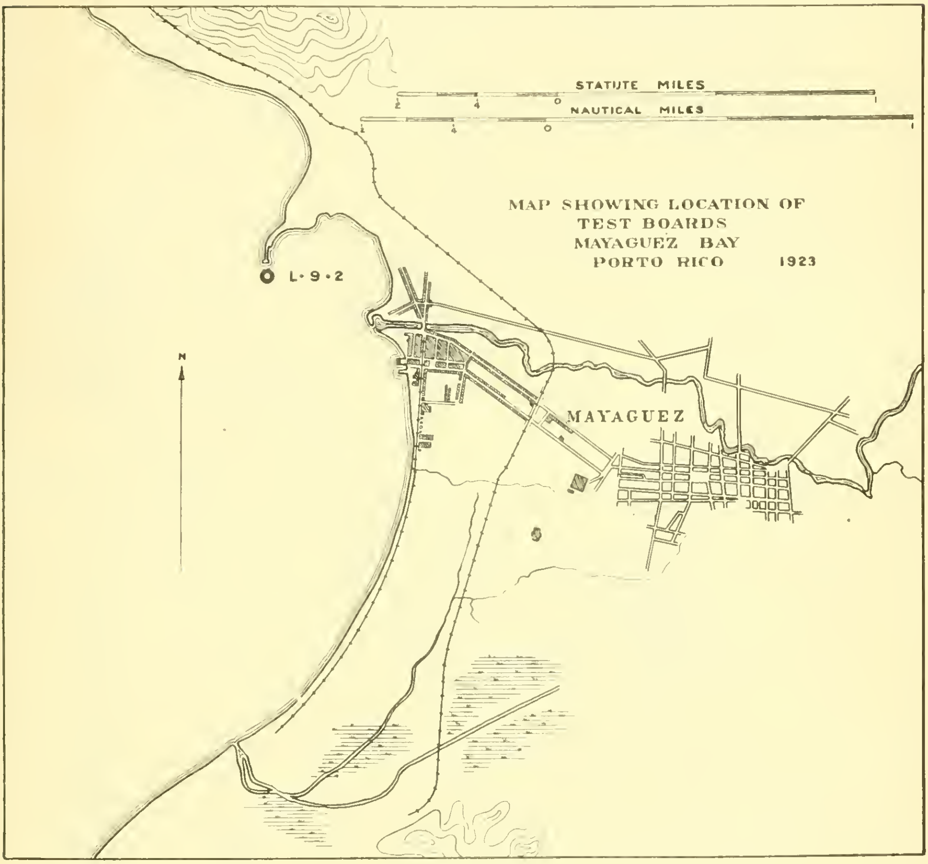


Fig. 162

from Pier 1, San Juan, was examined in which were found specimens of *Teredo atwoodi* and *Martesia*.

Chemical analyses of the water of San Juan Harbor at the Naval Station were made by the Insular Health Department, the results of which are shown in the table on page 441.

Methods of Protection

Creosote Impregnation—This method of protection has been in general use but has proved unsatisfactory. Sixty out of 1123 creosoted piles (19 pounds treatment) in Pier 2 of the New York and Porto Rico Steamship Co., San Juan, were completely destroyed by marine borers after 5 years' service. A similar experience was had with the creosoted sheet piling used to form the concrete dock wall at the Naval Station. Creosoted piles pro-

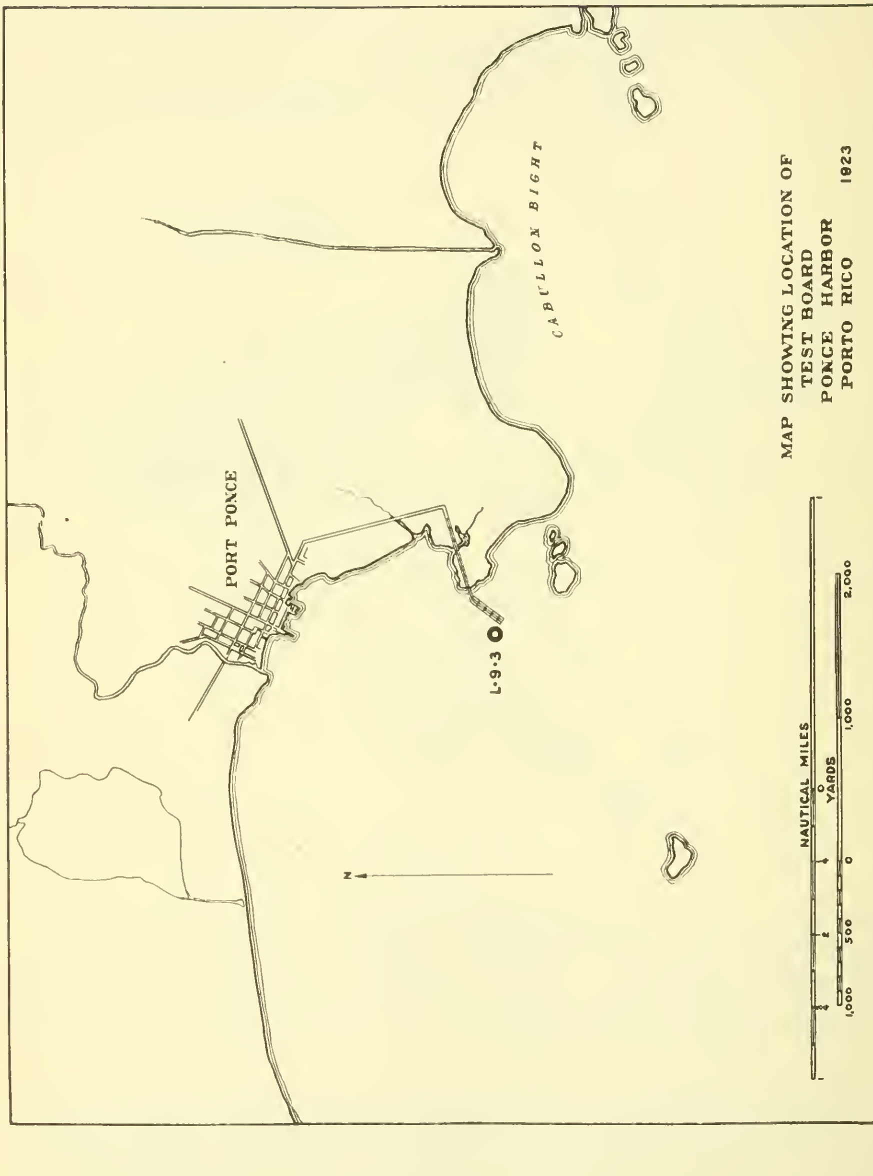

PORT PONCE
CABULLON BIGHT
L-9·3
N
MAP SHOWING LOCATION OF
TEST BOARD
PONCE HARBOR
PORTO RICO 1923
NAUTICAL MILES
YARDS
1,000 500 0 1,000 2,000

FIG. 163

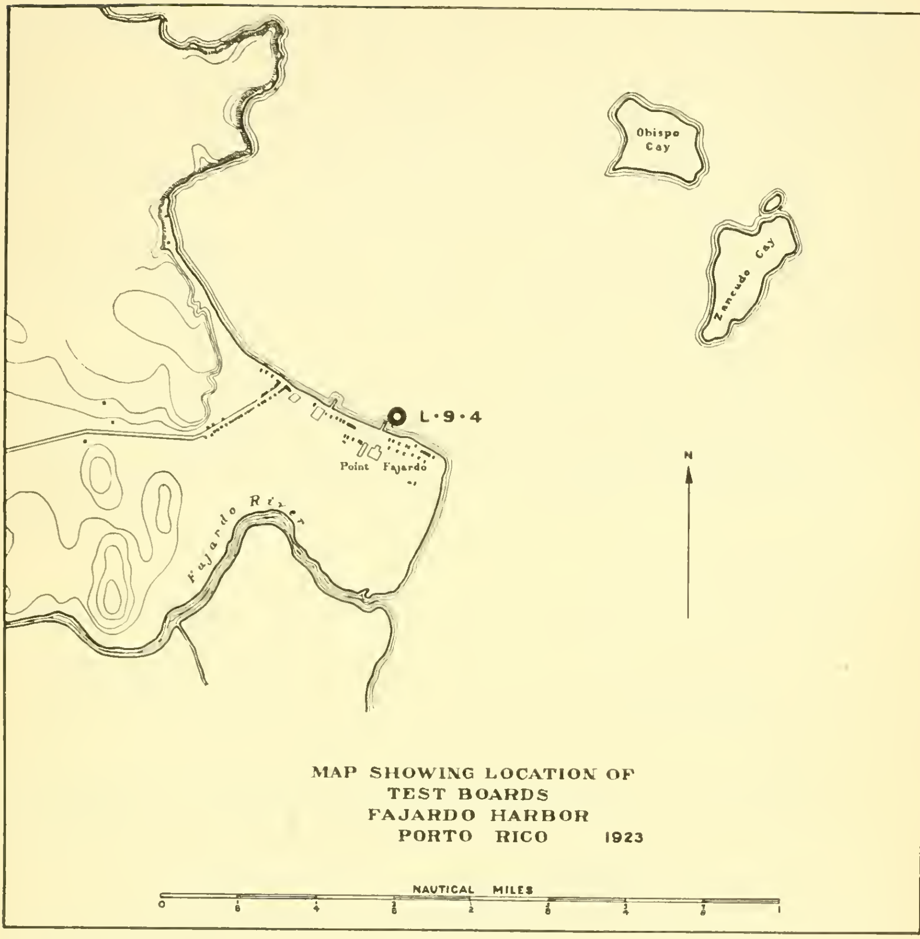


FIG. 164

ANALYSIS OF WATER OF SAN JUAN HARBOR

Date	CL parts per 1000	Dissolved Oxygen parts per 1,000,000	Hydrogen-ion Concentration	Temperature Fahrenheit (degrees)
1923				
March 17	20.85	5.79	8.4	77
April 8	20.50	5.40	8.4	81
April 30	19.95	6.18	8.5	82
May 16	19.15	2.65	8.5	82
May 25	19.45	3.43	8.5	86
May 28	20.05	3.24	8.5	84
May 31	21.25	5.01	8.5	85
June 5	21.15	9.82	8.5	84
June 9	20.45	5.69	8.5	84
June 14	21.45	4.41	8.5	82
June 18	21.45	4.42	8.5	83
June 21	21.55	4.61	8.5	84
June 28	19.95	3.53	8.5	85
July 6	21.15	4.42	8.5	85
July 14	20.95	4.52	8.5	85
August 14	19.95	3.53	8.5	84

tected by felt and sheet copper at the Lighthouse Depot, San Juan, lasted 15 years, but at the end of that time were completely riddled by borers. The San Antonio Docks of the New York and Porto Rico Steamship Co., San Juan, are of the marginal type, creosoted sheet piling and fill, with creosoted fender piles. According to the Lighthouse Service, the entire creosoted portion is infested with shipworms and rapid destruction is in progress. Piles treated with 20 pounds per cubic foot of creosote and driven in a wharf at San Juan in 1902 were damaged by *Limnoria* to a depth of 1½ inches in 18 months' time.

Two specimens of treated piles from San Juan were inspected by the committee's biologist and later chemically analyzed by Mr. Sumner R. Church of the Barrett Company's Laboratory with the results shown on page 124.

Armor—Copper sheathed piles were used in the Lighthouse Depot Pier, as noted above. No records of the kind and thickness of the metal are available. Pier 5, San Juan, was built in 1912 on timber piles encased in concrete with iron cylinders over all. The engineer depot pier at San Juan was built in 1921 on timber piles encased in concrete with steel cylinders over all.

Substitutes for Timber

Metal—There is no record of structures in Porto Rican waters built on cast or wrought iron piles.

Concrete—A number of concrete structures have been built, but construction records are lacking.

Conclusions

The investigations confirm the belief that marine borers, both shipworms and crustacean borers, are active throughout the entire year, and no period of immunity can therefore be expected in these waters as is the case in Atlantic and Gulf of Mexico harbors.

Timber impregnated with creosote does not have a satisfactory service record and, judging from the records and specimens available, is not apparently an economical method of protection.

Armor of cast iron would seem to offer the surest means of protection, though considering the comparatively low labor costs, it is possible that "scupper" nailing would also be an economical method.

The good record of wrought iron and cast iron in Florida waters justifies the consideration of these materials for important structures.

Records of concrete construction are not in sufficient detail to be included in this report.

CANAL ZONE

Water Conditions

Temperature, salinity and other characteristics of the water at Balboa Harbor, Miraflores Lake, Gatun Lake and Limon Bay are listed in the table compiled in the office of the Governor of the Canal Zone shown on the following page.

Temperature, Salinity and Other Characteristics of the Water at Balboa Harbor, Miraflores Lake, Gatun Lake and Limon Bay

Name of Body	Panama Bay Balboa Harbor	Miraflores Lake	Gatun Lake	Caribbean Sea Limon Bay
Kind	Salt	Brackish	Fresh	Salt
Degree salinity	Flood tide......1.019 Ebb tide.......1.022	Wet season — 100 to 200 per million. Dry season — 300 to 400 per million.	6 to 12 parts per million.	Aver. 1.020
Temperature	From 80 deg. F to 61 deg.—Av. 80 deg. F. Coldest in March.	Av. 84 deg. F.	From 89 deg. F. to 80 deg. F. Av. 84 deg.	From 87 deg. F. to 77 deg. F.—Av. 82 deg. F.
Purity	Clear. Slight contamination about docks, of oil and small wastes.	Clear. No contamination except silt from dredges working in Lake.	Clear. Silt in solution in Gaillard cut due to dredges.	Clear. Slight contamination of oil and wastes at docks.
Tides..........	Max. range.......21′ Av. range.......12.5′	None	Up to .25′ due to N. winds.	Max. range......2′.0 Av. range........0′.9
Currents	Tidal—From 0 to 1.0 knot.	Very slight current at times.	Slight current when freshets occur and Gatun Spillway operates.	Very slight — More outside breakwater as per pilot charts.
Depth, etc.	1 to 60′ deep—No real storms; wave action not pronounced.	1 to 45′ deep; rain squalls only; no real waves.	1 to 95′. Rain squalls only; waves 3′.	1 to 50′—rain squalls —occasional waves outside breakwater from northers.

Marine Borers

Past History—Marine borers, both crustacean and molluscan, are constantly present in the terminal waters and certain other portions of the Canal, with no seasonal differences in activity noted up to the date of these investigations. Species as follows have been identified by Mr. James Zetek, specialist in tropical entomology, Canal Zone:

Family Pholadidae

Pholas chiloensis Molina
Parapholas acuminata Conrad
Barnea crucigera Sowerby
Pholadidae tubifera Sowerby
Jouannetia pectinata Conrad
Martesia curta Sowerby
Martesia xylophaga Valenciennes
Xylotomea globosa Sowerby

Family Teredinidae

Bankia (*Neobankia*) *zeteki* Bartsch
Teredo (*Neoteredo*) *miraflora* Bartsch
Teredo (*Teredora*) *panamensis* Bartsch

The Teredinidae are all wood borers; the Pholadidae burrow into rocks and the three last named attack wood. The rapid destruction by shipworms of the greenheart timber (hitherto supposed to be immune from marine

borer attack) used in the locks, is an indication of the intensity of shipworm activity which is encountered in these waters.

Mr. James Zetek reports (April 29, 1923), on an inspection of piles removed from the Paraiso, in part as follows:

> "On the deck of the Ajax were four pilings that were pulled the day previous; of these three were creosoted. No live *Teredos* were found in these, but the examination was not very thorough. It was thought best to devote most time to such piles as showed *Teredos*. In the untreated pile was found one burrow, but the animal had died long ago and the burrow had no trace of it any more. This burrow was almost straight, the only deviation being near a knot. It was 19 inches long, and followed the grain of the wood, the anterior (head end, which has the bivalve shell) end lowermost and below the mud line. At this head end it was 1 inch in diameter. At 11 inches from this point it was ¾ inch in diameter. At a point 3 inches from the posterior (tail end) end it was 7/16 inch in diameter, and rapidly narrowed to the minute opening in the side of the piling. The anterior end was 3½ inches inward and 10 inches below the mud line. The extreme posterior part, where it turned abruptly to the surface of the piling, was 2½ inches from the surface.
>
> "Two more pilings were pulled up the 26th instant from the upper end of the dock. Both were non-creosoted. One of these did not appear to have any *Teredos*. The other one had many of them and some burrows with no animals present. We obtained four *Teredos* entire.
>
> "In every case the animal worked downward (positive geotropic). The reason for this is very plain. The very early stage of the *Teredo* is free-swimming, and its future development depends on the ability of this stage to become attached to the wood piling and start its burrow inward. This entrance is of extreme importance to the *Teredo* because just back of it is the posterior end of the mollusk, with its pallets and siphons. These two siphons (inhalent and exhalent) are the means by which the animal receives water, and after using it for respiration and for such microscopic food as it contains is able again to void it. Hence these openings must be between the mud line and the water line. The rest of the animal must find room elsewhere; if *Teredos* are extremely abundant this downward extension is not so evident.
>
> "The four *Teredos* measured 6 inches, 15 inches, 20 inches and 21 inches in length. This was after they were about 2 hours in preservative and it is quite probable they had become contracted a few inches. In one of these, measured in the field, this contraction actually took place and amounted to six (6) inches. The anterior end (which has the shell with which the mollusk makes its burrow) was from ¾ to 1 inch in diameter.
>
> "The posterior 3 or 4 inches of the mollusk tapers rapidly and terminates in the spoon-shaped pallets and the two siphons. This posterior section of the animal is protected by a hard calcareous casing, sometimes 1/16 inch thick. The opening in the piling, by means of which the siphons communicate with the water, has the shape and size of the figure "8." Sometimes the division is obliterated and the opening is either oval or circular. The calcareous lining does not cover the entire burrow, unless the wood is very soft and the number of *Teredos* large. When this lining does exist, it is always thickest at the posterior end.
>
> "As to the identity of the *Teredo*, I consider it to be the *Neoteredo miraflora* of Bartsch. The pallets are of this subgenus, but there is some variation in the shell which I attribute to senility. I am sending a good specimen to Doctor Bartsch for confirmation of the determination. All of our *miraflora* heretofore obtained have been much smaller in size.
>
> No young *Teredos* were found. All were mature, old specimens. As the piling used in the Paraiso dock came, in part, from Balboa and Cristobal, I am inclined to believe that some of this piling was already infested with fairly large *Teredos*, and as this piling was driven into its new place without much delay, these *Teredos* were able to survive and continue to live under the new conditions in the waters about Paraiso. Very young *Teredos*

are much more sensitive to changes in the environment, and I am of the belief that if any had been present they would have died.

"The fact that no young ones were present would indicate that the embryos cannot thrive in the water of such low salinity as at Paraiso. This would strengthen the hypothesis that the big *Teredos* found were in the timbers when these were brought to Paraiso.

"It may be that the young of these big *Teredos* move, due to the current caused by the lockages, to the locks where they find greater salinity and attack the greenheart timber of the lock sills."

Committee Investigations—A standard test board was maintained at Coco Solo (Fig. 165), under the supervision of the Public Works Officer of the Submarine Base. The blocks from this board were regularly examined and yielded results as follows:

YD-1501—Shipworm embryos appeared in quantities lying promiscuously on the surface of block 1, removed December 19. The succeeding blocks were all well filled with shipworms, the destruction being rapid. Species were identified as follows:

Teredo sp. D	*Teredo sp. F*
Teredo sp. Q	*Teredo sp. Z*
Teredo sp. G	*Bankia zeteki*
Teredo portoricensis	*Bankia sp. T*
Teredo clappi	*Bankia sp. V*

Individuals of *Teredo sp. G*, reaching a maximum length of 100 mm., at all times far exceeded in numbers all others, and those of *Teredo sp. D* and *Teredo sp. Q* attained maximum lengths of 150 mm. each. A new board of 1923 model was substituted for the old one April 4, and original blocks 8-24 inclusive, and replacement blocks 25-31 inclusive, were subjected to a careful examination. The results of this examination indicate that somewhere near the first of January the height of the season of activity is passed, and that shipworm embryos deposited after that date are stragglers whose growth is slow. The new blocks continued to show rapid destruction, all blocks being well filled with the exception of block 5-C, removed September 6, after one month's immersion, which for some undetermined reason, contained not a single specimen. *Teredo sp. G* maintained the numerical supremacy established in the blocks of the old board. *Limnoria* action was severe at times, many of the blocks being well scarred. *Martesia* was often present in varying quantities. Associated organisms were *Balanus*, Bryozoa, and *Ostrea*.

An inspection, made in November 1922, of the Old Dock at La Boca, which was constructed by the French in 1898, disclosed the presence of rock borers. (*Lithophaga aristata*). These animals were found burrowing in the concrete. The dock is supported by concrete caissons, 5 meters in diameter, sheathed with steel cylinders of 5 mm. thickness and entrance was effected at points where the steel shells had rusted through or been torn off by contact with some moving object.

Field Tests—Blocks bound with iron bands and wire, spaced at intervals of from ½ to 2½ inches, were submerged at Coco Solo, May 9, 1923. The results of these tests will be reported later.

Salinity and temperature observations of the water at Coco Solo are shown on Fig. 166.

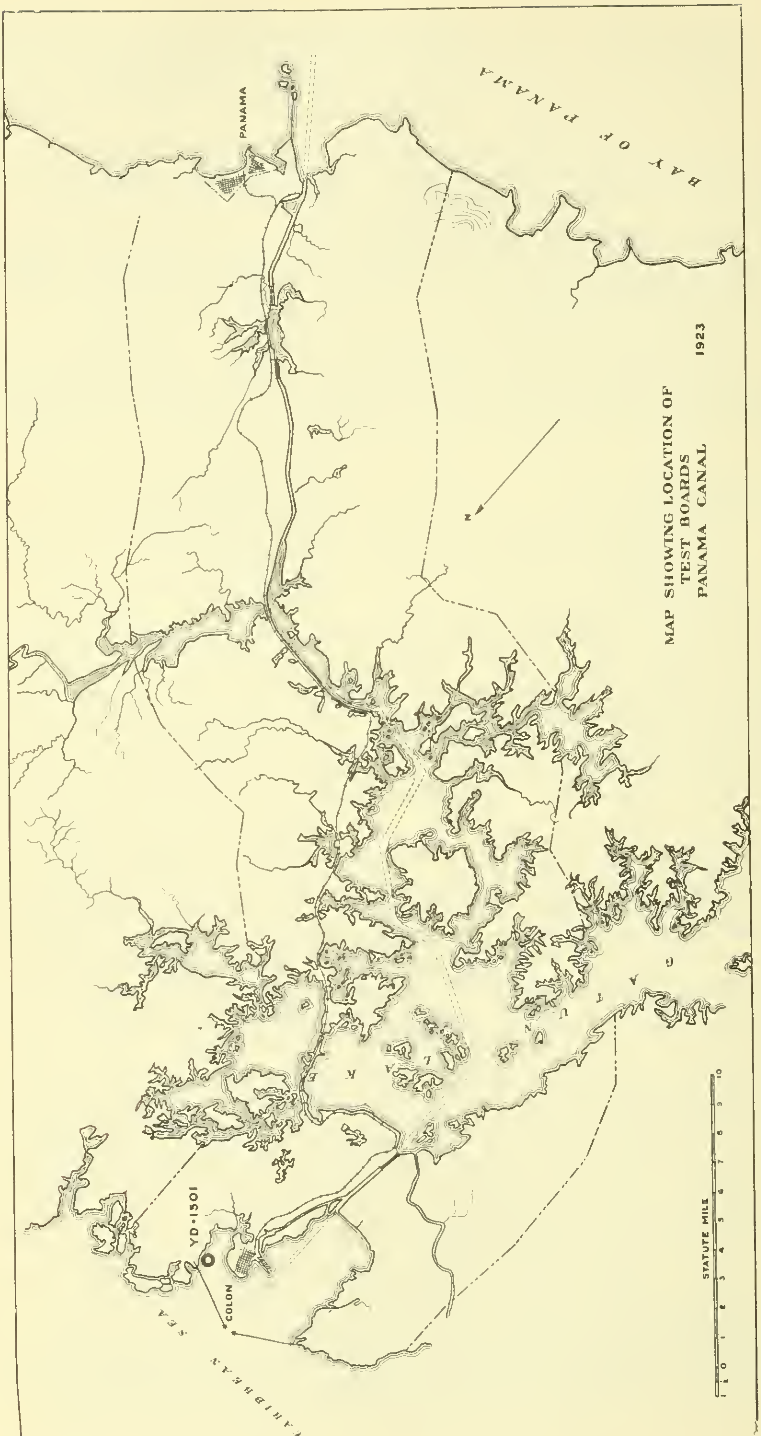

MAP SHOWING LOCATION OF
TEST BOARDS
PANAMA CANAL
1923
PANAMA
BAY OF PANAMA
GATUN LAKE
YD-1501
COLON
CARIBBEAN SEA
STATUTE MILE

FIG. 165

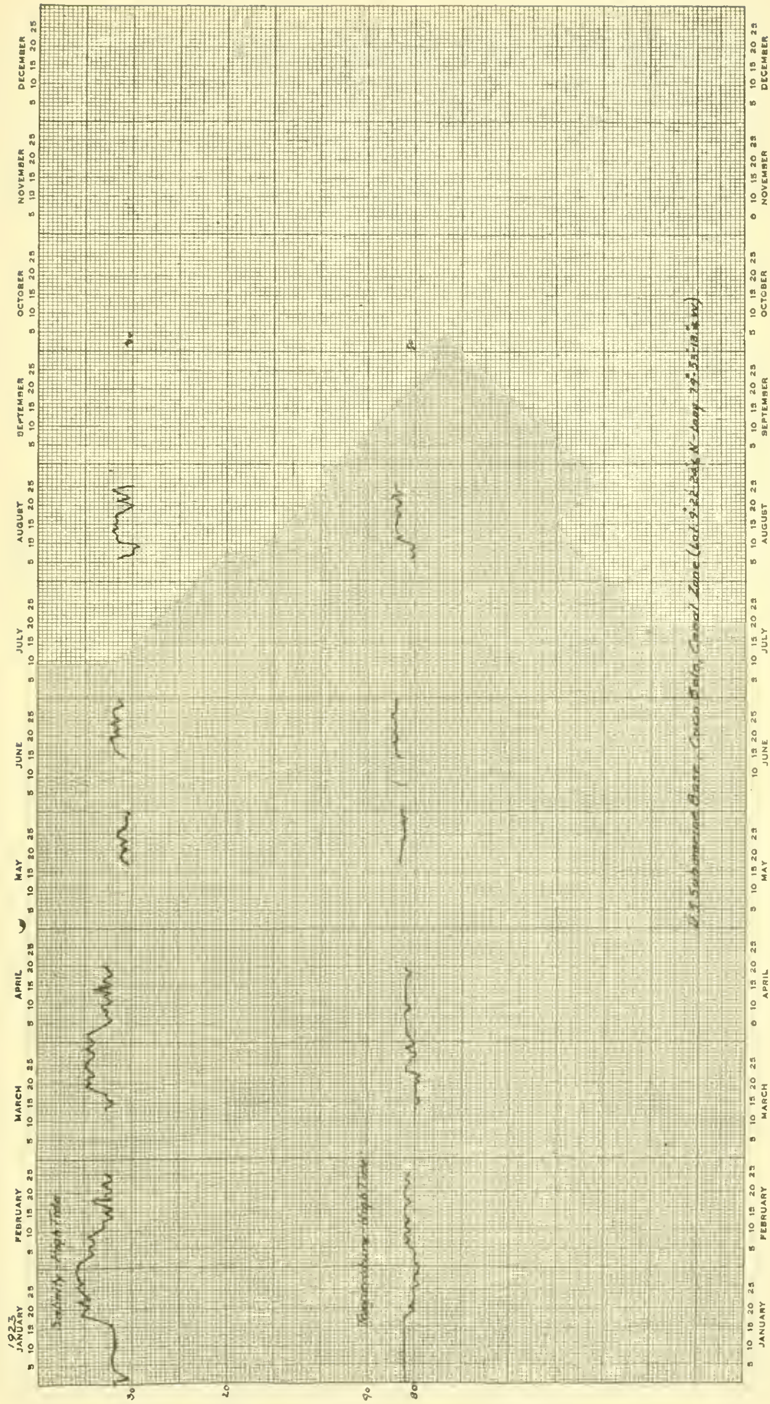


FIG. 166— SALINITY AND TEMPERATURE OBSERVATIONS, COCO SOLO, C. Z.

Methods of Protection

Creosote Impregnation—There are four finger piers on creosoted piles at the Submarine Base; otherwise the use of timber piles is for auxiliary purposes only. All piles are treated in accordance with Canal specifications requiring 16 pounds absorption per cubic foot and about 2 inches of penetration. Such work is of too recent construction to afford conclusions as to the efficacy of this treatment. Creosoted piles (kind and quantity of treatment unknown) driven by the French in 1905 in the old dock at La Boca were found on their removal in 1918 to have been attacked by shipworms.

Armor—Concrete. During the year 1912 an attempt was made to protect the piling of Pier No. 3, Colon, with concrete tubes in four-foot lengths which were slipped over the piles, the annular space being filled with grout. This did not pass the experimental stage as the replacement of pile structures with concrete was already under way. At Fort De Lesseps, Colon, another type of pile was used in 1916. Old 20-inch dredge pipe was placed over the piles after driving and the intervening space filled with concrete. No report of its present condition is at hand.

Armor—Metal. Cypress piles (12 inches square), sheathed with copper, were installed by the French in Old Pier 4, Colon. On removal it was found that most of them were in excellent condition. Where the sheathing had been torn off or broken, it was found that the action of salt water had formed copper chloride which in turn had soaked into the timber. The shipworms attacked the center of these piles but those portions containing copper chloride were untouched.

Substitutes for Timber

Metal—Two of the old piers at Cristobal, Nos. 3 and 5, were supported on 5-inch wrought iron screw piles exposed to salt water for a length of from 15 to 25 feet. These had good substantial cores when pulled. The steel girders supporting the concrete floor of the Old French Dock at La Boca are exposed to the salt spray and are at present badly rusted and pitted. All protected steel is in good condition. At Coco Solo metal is used on waterfront structures only for fittings such as manhole frames, covers, bolts, etc., black and galvanized wrought iron pipes, and cast iron pipes. The exposed metal is, in general, covered with bitumastic enamel. Numerous wrought iron pipes, both black and enamel, where not available for frequent inspections have become unfit during the past 5 years. On the other hand, cast iron shows little, if any, deterioration.

Concrete—Accurate and detailed descriptions of the concrete structures of the Canal Zone, the methods and materials employed in their construction are to be found in the publicly issued reports of the Canal Commission. All such structures are said to be in good condition.

PACIFIC ISLANDS

General Description

The harbors included in this report are Honolulu, Pearl Harbor, Nawiliwili, Hawaiian Territory; Tutuila, Samoa, and Cavite, Philippine Islands.

In general the Hawaiian Islands all lie within the path of the northeast trade winds which prevail throughout the year with interruptions, during the winter months, by variable winds, or by "Konas," the local name for

strong southerly or southwesterly winds, the latter lasting from a few hours to two or three days and attended by rain. The streams may be classed as mountain torrents and few are navigable for small boats. Rainfall varies greatly under the influence of winds and mountains, and in general occurs on the windward side of the islands and during the winter months. The average tides vary from 1 to 2 feet and the tidal currents are considered to be negligible.

Honolulu Harbor (Fig. 167), the most important port of the islands, is entered through a coral reef, the channel being 5/8 mile long and 400 feet

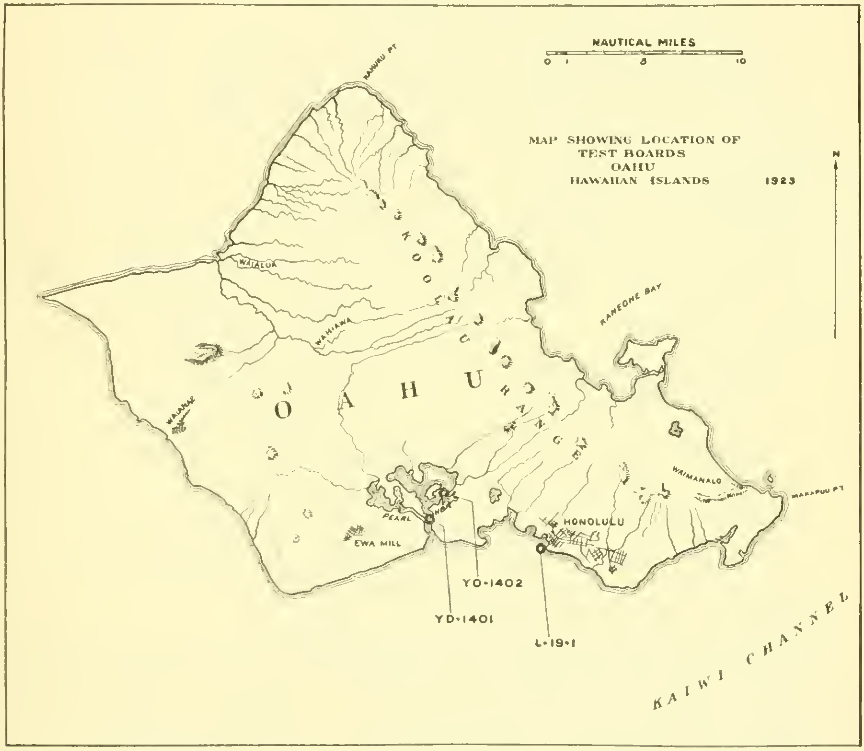


Fig. 167

wide. The harbor is about 1/2 mile long and 1,000 to 2,000 feet wide. Both the harbor and channel have been dredged to a depth of 35 feet. The depths alongside the principal wharves are from 20 to 35 feet.

Pearl Harbor, sometimes known as the Pearl Lochs, is situated on the southern coast of the Island of Oahu, Territory of Hawaii, about 7 miles southwest of Honolulu. Pearl Harbor is just within the tropics, its geographical position being latitude 21° 21′ North, longitude 157° 57′ West. The harbor is almost completely landlocked, consisting of a number of "lochs" separated by low coral rock peninsulas and having one narrow and somewhat tortuous channel to sea which has been straightened and deepened by dredging. The minimum depth in the channel is 35 feet at mean low water. No ocean swells are felt in the harbor, the roughest water experi-

enced in the lochs being no more than a "harbor chop." The water in the harbor is clear sea water, the salinity and clarity varying but little except when occasional heavy rains in the mountainous region, draining into the harbor, cause a reduction in the salt content and the presence of a noticeable amount of silt for a few days. Such rains do not occur more than once or twice a year. There is little sewage pollution except in the immediate vicinity of the Navy Yard, and there is no serious pollution from chemical wastes. The water in the vicinity of the Navy Yard is always more or less seriously polluted with oil from oil-burning vessels and submarines. The following table gives certain pertinent data on the water at Pearl Harbor:

Degree of salinity: (No seasonal change.)

Maximum 25.6 parts per thousand of total solids.
Minimum 20.2 parts per thousand of total solids.
Average 23.0 parts per thousand of total solids.

Temperature:

Maximum 88° Fahr.
Minimum 74° Fahr.
Average 81° Fahr.
Maxima occur in July, August and September, and minima in January, February and March.

Tides:

Maximum range 3 feet.
Average range 2 feet.

Currents:

Tidal—maximum 2 knots.

Depth:

Channel, 35 feet at mean low water.
Maximum depth in deep pockets in entrance channel 138 feet.

Storms:

Occur only in winter months and are infrequent.

Nawiliwili Bay (Fig. 168), at the southeast end of the Island of Kauai, is about ¾ mile wide between Ninini Point and Carter Point, and indents the coast about ⅞ mile. The depth at the wharf at Nawiliwili village is 4 feet.

Pago Pago Bay, Samoa, a direct inlet from the Pacific, is of ocean salinity. The water is generally clear but receives some sewage. The average range of tide is 3.6 feet; the average temperature 78° Fahr. The maximum velocity of tidal currents is estimated to be about 2 miles. There are depths in the bay ranging from 6 to 180 feet. The bay is exposed to the trade winds, but not to hurricanes as a rule, which generally come from the north and west. Waves 8 feet high were observed in 1916, but ordinarily there are practically no waves.

Cavite, Philippine Islands, the site of the United States Navy Yard, is about 7½ miles southwest of Manila. The harbor is formed by a low peninsula, the northern extremity of which, Sangley Point, is reported to be extending at the rate of 35 feet per year.

Marine Borers

Past History—Marine borers were known to be present constantly in

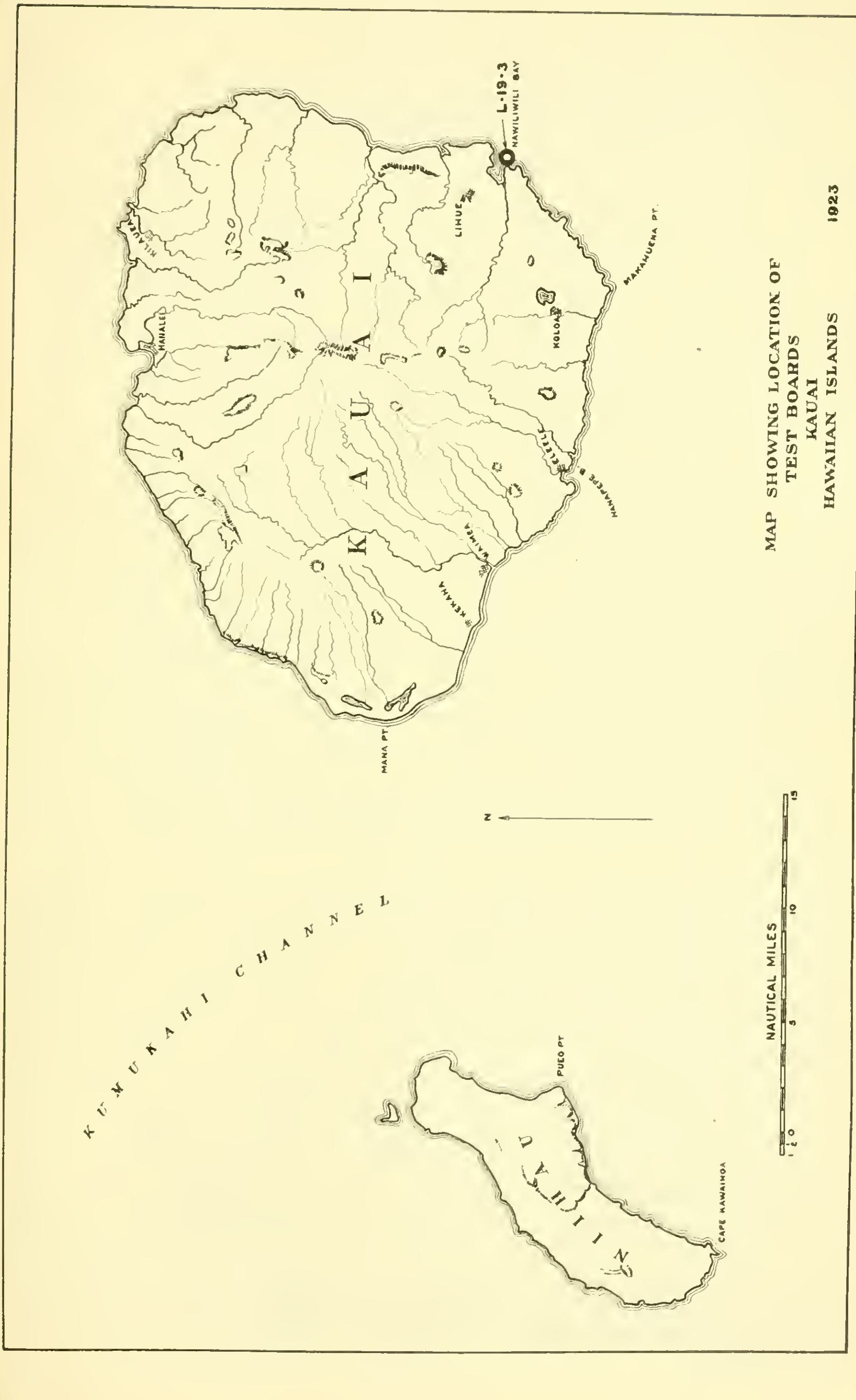

MAP SHOWING LOCATION OF
TEST BOARDS
KAUAI
HAWAIIAN ISLANDS
1923
L·19·3
NAWILIWILI BAY
LIHUE
KOLOA
MAKAHUENA PT.
WAIMEA
KEKAHA
MANA PT
HANALEI
KILAUEA
KAUAI
KUMUKAHI CHANNEL
NIIHAU
PUEO PT
CAPE KAWAIHOA
NAUTICAL MILES
N

FIG. 168

all the waters included in this report, and up to the time of these investigations no seasonal differences in activity had been remarked.

In the Hawaiian district untreated timber was estimated to last not to exceed two years—in some instances not over six months, and is therefore not exposed to sea water except in temporary structures.

Committee Investigations—Standard test boards were installed as follows:

Location	Symbol	Department Maintaining	Date Installed	Bottom of Board to Mud Line (Feet)	Bottom of Board to M. L. W. (Feet)
Honolulu Harbor, Pier 4	L-19-1	Lighthouse Service	Nov. 16, 1922	0.5	20.5
Pearl Harbor, Coaling Plant	YD-1401	Navy	Sept. 1, 1922	0.3	20.1
Pearl Harbor, Magazine Island	YD-1402	Navy	Sept. 1, 1922	0.5	20.3
Nawiliwili, Kauai	L-19-3	Army	Feb. 1, 1923	1.5	7.5
Tutuila, Samoa Station Wharf Pago Pago Harbor	YD-S-1	Navy	Nov. 16, 1922	......	......
Cavite, P. I	YD-1601	Navy	April 15, 1923	......	......

A report of the results of the examinations of test blocks follows:

L-19-1—Block 2, removed December 15, 1922, contained about 25 shipworms too immature to identify. Block 4, removed one month later, contained about 5 specimens of *Teredo parksi* to the square inch, with tubes up to 2 cm. in length. Blocks 5 and 6 showed a similar attack, *Teredo affinis* being observed in the latter. In block 7 the attack increased to about three times the intensity observed in previous blocks. *Teredo affinis* was predominant in blocks 8 to 11 inclusive, somewhat diminished in numbers and with tubes reaching a length of 90 mm. *Teredo parksi* reached a length of 190 mm., as observed in block 24, removed November 15, and the last reported. *Limnoria* action having become heavy in block 7, increased in intensity to such an extent that many of the succeeding blocks were received in a crumbling state. Associated organisms were *Balanus*, Bryozoa (*Schizoporella*), tube worms, and *Corophium*.

YD-1401—A few minute shipworm punctures were observed in blocks 1 and 2, removed September 15 and October 2, 1922, respectively. A fairly heavy settlement occurred on blocks 3 and 4. Blocks 5 and 6, removed November 16, contained about 10 specimens of *Teredo parksi* per square inch of surface, the tubes in the latter reaching a length of 8 cm. A number of specimens were found passing from block 8 to the supporting board, the damage in this and succeeding blocks being severe. On May 1, 1923, a new test piece of 1923 model was substituted for the old one. A few punctures were observed in the first block, which was removed June 1. Succeeding blocks were well filled with *Teredo parksi*, with lengths of tubes up to 185 mm. The last series reported were removed November 3, 1923. An examination of the old test specimen, including the remaining original (Nos. 16-24) and replacement blocks (25-39), leads to the following conclusions:

The breeding season of *Teredo parksi* at this locality reaches its height in September and October (possibly earlier, as we have no data prior to the middle of September), progressively decreasing during the period November-March, and approaching or reaching zero in April.

Teredo parksi is predominant; *Teredo affinis* and *Teredo diegensis* occur in small numbers.

Limnoria attack on the original blocks was not especially heavy, some of the blocks showing but little damage. *Limnoria* attack on the replacement blocks was for some reason decidedly worse than on the original blocks. The surfaces of Nos. 25-30 were badly attacked and parts had crumbled. Edges of No. 27 had completely crumbled. The *Teredo* burrows in these blocks had their ends partly exposed. *Limnoria* attack on blocks after No. 31 was moderate. Specimens of *Martesia striata* were present occasionally in the original blocks. There was a fairly heavy covering of *Balanus*, Bryozoa and tubeworms on all blocks originally placed.

YD-1402—The shipworm attack on these blocks was similar to that on YD-1401, perhaps slightly more intense. The *Limnoria* attack was much heavier than at YD-1401. Blocks 16-24 were badly destroyed, the excavations having uncovered the *Teredo* burrows. The surfaces of succeeding blocks up to No. 32 were badly attacked. Associated organisms were the same as those observed on the blocks from YD-1401. The last blocks reported were removed November 30, 1923.

The Committee received from the Public Works Officer, U. S. Naval Station, Pearl Harbor, Territory Hawaii, specimens of rock-boring mollusks, identified by Professor Edmonson of the University of Hawaii as *Rocellaria lamellosa*. These specimens were found in coral rock and were taken from the dredging for the North Quay Wall and Pier, Pearl Harbor.

L-19-3—Shipworm punctures averaging about 5 to the square inch and not exceeding 2 mm. in depth, were found on block 2, removed March 1, 1923. Block 3 was similarly affected; block 4 showed an increase in attack of about 100 per cent, and block 5, removed April 16, contained about five times the number of specimens noted in block 4. Two species were observed, viz., *Teredo parksi* and *Teredo affinis* Deshayes. Succeeding blocks were riddled, the destruction being practically complete. The tubes reached a length of 60 mm. in block 7. The last block examined was No. 24, removed February 1, 1924. *Limnoria*, appearing at first in small numbers, became abundant in block 14 and succeeding ones. Occasional specimens of *Martesia* were observed. The only associated organism reported was green Algae.

YD-S-1—Shipworm punctures were observed on block 1, removed December 1, 1922. The attack on succeeding blocks increased in intensity. Only 7 blocks were examined, the remaining blocks together with the supporting board having been lost, on account of damage by borers. A new test piece of 1923 model was immersed June 1, 1923. Blocks 1 of the new series, removed July 2, showed 30 to 40 shipworm punctures up to 20 mm. deep. Block 2, removed July 30, contained 30 to 40 specimens per square inch of surface, with burrows up to 60 mm. in length. Block 3 was riddled near the surfaces with burrows of 130 mm. maximum length, and block 4, removed October 1, was completely filled, the tubes reaching a length of 300 mm. The last blocks inspected were removed January 7, 1924. *Teredo parksi* was predominant, with *Teredo samoaensis* and *Teredo furcillatus* occurring in small numbers. *Limnoria* action at times was quite severe. Associated organisms were *Balanus*, Bryozoa (*Schizoporella*), *Corophium* and tube worms.

YD-1601—These blocks, due to their long time in transit, were generally received in poor condition for inspection. In all, seventeen blocks (Nos. 2-18) have been reported. Damage by *Martesia* was found to be quite

heavy. The action of *Teredo parski* was also severe. No *Limnoria* action was noted.

Methods of Protection

Creosote Impregnation and Pile Coating—The use of creosoted piling in Hawaiian waters has been abandoned by the Army as being unsatisfactory except for temporary structures. Unfortunately there is available no record of treatment or of oil analyses.

In the reconstruction in May, 1918, of a small quay wall at Pier 4, Honolulu, the piles were treated with three heavy coats of asphalt paint, sanded after each coat. In January, 1921, these piles were eaten away about 75 per cent in the section between high and low water, rendering the wharf unsafe. Both *Limnoria* and shipworm action caused the damage.

The report of the Public Works Officer at Pearl Harbor follows:

> "Douglas fir timber piles in lengths varying from 50 feet to 90 feet have been much used in the construction of wharves at Pearl Harbor. Untreated piles are used only in such structures as will permit of the piles being entirely below the mud line, and therefore not exposed to borers. Metal sheathed untreated piles, creosoted piles, or concrete piles have been used in all locations where the piles are exposed to the action of borers.
>
> "Untreated timber piles are proving successful in the foundations of the coaling plant wharf, the outboard ends of the torpedo boat piers, and the original part of 1010 wharf, in all of which structures the piles are cut off below the mud line and capped with a concrete column. The coaling plant wharf was built in 1912, 1913 and 1914 by Yard labor; the torpedo boat piers in 1916 and 1917 under contract 2169; and 1010 wharf in 1916, 1917, 1918 and 1919 under contract 2178. The foundations of these structures are giving no trouble. There is no available data on the life of untreated piles at Pearl Harbor completely submerged and cut off below the mud line. Presumably they will last indefinitely. The columns of such structures should, however, be frequently inspected by a diver to prevent undetected exposure of the piles to borers due to erosion of the bottom. Some work will probably be needed at the coaling plant wharf in the near future to prevent such exposure of the piles, a recent inspection by a diver showing some of the piles very nearly exposed. Such erosion is especially likely where dredging has been done in the channel near such structures. Untreated timber piles when used in an ordinary timber wharf with no protection from borers have a life of from 6 to 12 months at Pearl Harbor. Untreated piling costs from 40 to 65 cents per foot delivered but not driven.
>
> "Copper sheathed untreated timber piles and untreated timber piles sheathed with yellow metal have been used in the construction of the hospital wharf, commandant's boat landing, and boat landing at Magazine Island. The dates of construction and present age of these structures are:

WHARF	DATE OF CONSTRUCTION	AGE
Boat Landing No. 3	1917	7 years
Boat Landing Magazine Island	1916	8 years
Hospital Wharf	1916	8 years

> "Sheathed piles in these structures have stood up well except when an injury to the sheathing has permitted the entry of borers which have rapidly destroyed the pile. Sheathed piles do not stand hard driving well and their use in important structures is not recommended.
>
> "Creosoted piles were used in the construction of the wharves listed below:

WHARF	DATE OF CONSTRUCTION	AGE
Sub. Base Piers 1 and 2	1917, 18, 19	5, 6, 7 years
Commandant's Boat House	1918	6 years
Air Station Wharf	1922	2 years
Air Station Boat Landing	1922	2 years

"The piles stand up well except where a large surface injury permits the entry of borers. The ordinary life of such piling in Pearl Harbor is not yet known, although it is known that in creosoted pile wharves an occasional pile will have to be replaced when the structure is about two years old and replacements must be made from time to time thereafter when an injury to a pile permits borers to reach the uncreosoted wood. The specifications under which the above structures were built do not call for any special care in the handling of creosoted piles—the use of spike dogs in the rafting of piles is not prohibited, for instance. Care is taken, however, in the design of the structures to have no bolt holes below the water line and to have all bracing above the water line. In the case of the Air Station Wharf at Ford Island, the bracing has been placed about 6 inches too low, as it is wet at high water and the lower edges of the members have been badly attacked by *Limnoria.* The piles have apparently not been attacked. Creosoted piling used at Pearl Harbor has been bought under specifications calling for treatment by the vacuum and pressure process and requiring the use of from 12 to 14 pounds of creosote per cubic foot of impregnated wood and a depth of penetration of the oils of 7/8 inch. Creosoted piling costs from $0.90 to $1.20 per lineal foot.

"Treatment of cuts, daps, and notches in creosoted piles and of the timber of the superstructure of wooden wharves with carbolineum applied with a brush has been used to a limited extent. There is no data available on the cost of such treatment or on its effectiveness."

Armor—Sheathing with yellow metal has been used by the Lighthouse Service on wood spars for this vicinity in times past, but its use has been abandoned because it was easily damaged and as it was found that the slightest break in the metal was sufficient to admit borers in destructive numbers. The Army finds that protection by copper or yellow metal over felt is unsatisfactory, as the metal is frequently torn or perforated.

Timber piles protected with steel casing, the annular space filled with concrete, were used in the old quarantine wharf at Honolulu, constructed in 1906. When removed in 1917 it was found that portions of the piles had been eaten away at or near the mud line, and it was evident that the casing had not penetrated below the bottom to a sufficient depth to prevent the washing away of the fresh concrete and the entrance of the borers.

Substitutes for Timber

Concrete—Of the concrete structures built by the Army in the Hawaiian district none antedate 1910. A recent report states that no apparent deterioration of reinforced concrete structures due to salt water exposure has occurred where the steel reinforcement was not badly rusted when placed and where the reinforcement has at least one inch of concrete protection.

The report of the Navy Department on concrete structures is as follows:

"There are numerous reinforced concrete waterfront structures at the Pearl Harbor Navy Yard. The principal ones being the coaling plant wharf, torpedo boat piers, 1010 wharf, ammunition depot wharf, and the new oil wharf at Merry Point. Climatic and other conditions favor these structures as they are exposed to but little rain, are hardly ever splashed by salt spray, and are never subjected to the trying effects of alternate freezing and thawing. As will be mentioned later, the only serious signs of deterioration that are evident on any of these structures are spalling of reinforced concrete piles and cylinders a short distance above high water mark. The decks, girders, beams, and in general the floor and superstructures are all in good condition.

"Precast concrete piles have been used at Pearl Harbor in the construction of the ammunition depot wharf, torpedo boat piers, the fuel oil wharf at Merry Point, and in constructing additions to 1010 wharf under contract

No. 4591. These wharf jobs are treated below in some detail in a series of subparagraphs.

"The Ammunition Depot wharf was started in October, 1912, and completed in September, 1914, the present age of the structure, therefore, being from 10 to 12 years. Two pile designs were used in the work. The majority of the piles are of octagonal design, cross section being a regular octagon whose inscribed circle is 16 inches in diameter at the butt and 11 inches in diameter at the tip. The piles are reinforced with 12 ¾-inch round rods equally spaced around the circumference of a circle of such diameter that there is 2 inches of concrete covering the rods. This 2-inch cover is from the face of the pile to the outer face of the rod—not the distance to the center of the rod. The rods run the entire length of the pile, which is further reinforced with spiral wrapping of number 6 wire wound on a 4-inch pitch. The mix, period of curing and method of driving used on these piles are not known. The second design was used in making two 40-foot piles with square cross section 14 inches by 14 inches at the butt and 12 inches by 12 inches at the tip. They were reinforced with eight 1-inch round bars, 4 in the corners and 4 in the center of each face of the pile, and had a spiral wrapping of number 6 wire wound on a 4-inch pitch. The mix, period of curing and method of driving of these piles are not known. Both octagonal and square piles have about 6 feet of their length exposed to air and from 2 to 30 feet exposed to water. The octagonal piles, of which there are 48, are all in good condition, while the square piles, of which there are only two, are both in bad condition, the concrete having spalled off all faces about 18 inches above high water mark so as to expose the reinforcing steel, which is very badly rusted. These piles require immediate major repairs.

"Torpedo boat piers were built under contract No. 2169 in 1916 and 1917 and are, therefore, from 7 to 8 years old. The inboard sections of these piles are supported on precast reinforced concrete piles varying in length from 34 to 37 feet. The piles are square cross section, 16 inches by 16 inches, except under the railroad tracks, where they are 18 inches by 18 inches. The piles are reinforced with eight 1¼-inch round rods, the corner rods running the full length of the pile, while rods in the center of the faces extend from the top for a length of 9 feet 3 inches. The piles have ¼-inch round hoops and diagonal ties spaced 2 feet 6 inches center to center, except that at the top the hoops are spaced 6 inches center to center to withstand driving stresses. The reinforcing is placed so that there is 1⅞ inches of concrete over the outside of the main longitudinal reinforcement. The concrete was 1:2:3½ mix, the sand being a mixture of two parts crusher sand with three parts Waianae; the rock was 1-inch. The piles were driven with an ordinary steam hammer having a 5,000-pound ram falling about 3½ feet. The piles were not jetted or churned. A number of piles were rejected for transverse cracks developing during the driving. The present condition of these piles is not satisfactory. There are in all 207 piles in the three piers and of this number 45 are more or less seriously spalled between the water line and the deck of the wharf. The piles are in good condition below the water line. The spalling is similar to that described as having taken place in the square piles of the ammunition depot wharf.

"Merry Point wharf and extensions to 1010 wharf. These are new structures, the extensions to 1010 wharf being as yet incomplete. For complete data on the lengthy and involved question of the reinforced concrete piles used in these structures, the reader is referred to the correspondence on contract No. 4650, under which the fuel oil wharf was constructed, and contract No. 4591, under which the 1010 wharf is being lengthened. The piles are as yet too new to give any valuable data as to their durability. Extremely valuable data can be obtained from these contracts, however, on the question of casting, curing, lifting and driving concrete piles. Attention is particularly invited to a Board report on contract No. 4650, dated November 22, 1923.

"In the casting of all the concrete piles mentioned above, standard brands of Government tested cement were used. The aggregates were crushed lava rock and Waiana sand, while the water was from an Artesian well at

Moanalua. This water is potable, has a salt content of under six grains per gallon, and there is no question that it is a good water for mixing concrete. The spalling noted on the square piles of the ammunition depot wharf and the square piles of the torpedo boat wharves is believed to be due to insufficient cover over the reinforcing material and possibly due to the use of a concrete which is not as dense and impervious as it should be. Further search is being made through old files in an endeavor to get details of the mixes used on the Ammunition Depot wharf job, as the good condition of the octagonal piles and the poor condition of the square piles indicate that valuable information may be obtained from this structure. Possibly the Bureau's files might yield information of value on this matter.

"Sheet piling and precast cylinders. There is no reinforced concrete sheet piling of any consequence at Pearl Harbor. Precast cylinders were used, however, in the construction of the coaling plant wharf and the outboard ends of the torpedo boat wharves.

"The coaling plant wharf was constructed by Yard labor in 1912, 1913, 1914 and 1915. The structure is, therefore, from 9 to 12 years old. The cylinders used in the construction of this wharf are from 31 feet to 35 feet in length, 4 feet in external diameter and 2 feet 8 inches internal diameter at the upper section, while the lower bell ends which fit over clusters of untreated timber piles are 10 feet in external diameter and 8 feet 8 inches internal diameter. Both the bell end and the 4 foot column sections of the cylinders are 8 inches thick and are reinforced with 1 inch square rods running vertically and ½ inch round rods as circumferential reinforcement. The details of the mix used in the precast cylinders are unknown. The general present condition of the cylinders is good except that the cylinders are spalling in a few places where the reinforcement evidently got out of place in the form so that there is only a fraction of an inch of concrete over it instead of the designed amount of cover.

"The torpedo boat wharf precast cylinders are shown in detail on Y. & D. drawing No. 64303. The design follows the above outlined features of the cylinders on the coaling plant wharf very closely. The mix was 1:2:3½, the sand being two parts crusher sand and three parts Waianae; the rock was 1 inch crushed lava of the usual grade. These cylinders are now in excellent condition.

"Precast columns and struts grouted into place were used in the construction of 1010 wharf and the outboard ends of the torpedo boat piers. Details of these columns and struts are shown on contract drawings of contract No. 2169, under which the torpedo boat piers were built, and contract No. 2178, covering the construction of 1010 wharf. These precast members are all in good condition.

"The cylinders mentioned above were filled with tremie concrete, which will be treated in a later section of this report.

"Poured-in-place cylinders or piers were constructed inside the precast concrete cylinders described above under the heading of coaling plant wharf and torpedo boat piers. These cylinders were made by filling the precast cylinders with tremie concrete and will, therefore, be treated in a later section of this report, under the heading of tremie concrete.

"Decks and superstructures—Girders, arches, beams, slabs and walls of reinforced concrete wharves at Pearl Harbor are of usual standard design. The superstructure of the torpedo boat wharves was made with 1:2¼:4 concrete. The superstructure of 1010 wharf and of Merry Point wharf were made with the same mix. The superstructures of all these wharves are in excellent condition, there being no evidence of spalling except in very few cases where the reinforcement has evidently been out of place so as to have practically no concrete covering protecting it. It is understood that on San Francisco Bay serious trouble has been experienced recently with spalling on the underside of waterfront structures, and the Pearl Harbor wharves have therefore been carefully examined for evidences of such spalling in order that this report might take cognizance of trouble of this kind if it existed. It is believed that the satisfactory condition of the Pearl Harbor structures is largely due to climatic conditions and the fact that seas in the harbor are rarely heavy enough to cause serious splashing

up against the undersides of wharves. No protective coating of bitumen or other similar material has been applied to the undersides of these wharves.

"Tremie concrete has been used at Pearl Harbor in filling spaces between precast sections of the dry dock and in filling precast cylinders at the coaling plant wharf and the torpedo boat piers and in attaching precast columns to untreated wooden pile clusters in the foundations of 1010 wharf.

"In the dry dock work tremie concrete was of 1:2:3½ mix, each cubic foot of sand being composed of ⅓ cubic foot crusher sand and ⅔ cubic foot of crushed rock screenings.

"The coaling plant wharf cylinders were filled with tremie concrete of the same mix used in the dry dock work.

"Torpedo boat wharf precast cylinders were filled with tremie concrete of 1:2:3½ mix, the sand being two parts crusher sand and three parts Waianae sand.

"1010 wharf precast members were attached to wooden piles with tremie concrete of 1:2:3½ mix, the sand being two parts crusher sand and three parts Waianae.

"Tremie concrete structures which have recently been examined by a diver have been found in good condition except that at the coaling plant, as has been noted above, erosion of the bottom threatens to expose some of the wooden piles. This, of course, is not the fault of the tremie concrete.

"Methods of protecting concrete structures have until very recently consisted simply of the usual precautions in mixing and placing. There is, of course, no difficulty due to freezing at Pearl Harbor, and satisfactory concrete is insured by using tested materials, keeping the water content of the mix down to a reasonable amount, and keeping the new concrete wet during the period of curing. In the dry season in Hawaii the proper curing of concrete offers a serious problem, as the material dries out very quickly and must be almost constantly sprayed if it can not be buried in wet sand or wet sawdust. The proper curing of concrete piles is particularly difficult. Methods used successfully are described in detail in the correspondence on contract No. 4650, which has been referred to previously. There are no records of the use of water-proofing compounds at Pearl Harbor, nor has the cement gun been used for "guniting" joints, surfaces, etc. The practice of painting concrete piles with asphalt is being commenced at Pearl Harbor with contract No. 4591. This job is now under way and no data are available as to the protection afforded by such painting."

A recent report by the Navy on concrete structures in Pago Pago harbor, Tutuila, Samoa, follows:

"Two concrete water-front structures exist: The Customs Wharf and the Governor's Landing. The former consists of precast piles with concrete walls hung between, and is 112 feet long. The latter is a pier of which only the outboard end is of concrete construction; this was poured in place, and consists of piles and a beam and girder deck."

"Precast Piles, Customs Wharf. Piles are 8 inches square at the point and 20 inches square at the butt. Their average length is 30 feet, and they were installed in 1919 and 1920, in 12 to 17 feet of water (low tide); the tide range is 3.6 feet, and the piles show about 2 feet above high water. A local volcanic blue stone was used in the concrete, which has previously been used with success; coral sand washed in fresh water; and Atlas Portland cement, Navy specifications, and in good condition. The water used was from the Station reservoir, and was clear and pure. Reinforcement was ½ and ¾ inch square twisted bars, wire brushed before placing, and 2½ inches concrete cover was provided. The mix was 1:2:4, and gave a smooth appearance. The curing of the piles was done in the open; they were wet when the forms were removed, then left to the tropical climate, with frequent showers, for 30 days. They were supported along their entire length upon 2 x 12 boards resting on 6 x 6 sills. No cracks developed. Driving was done with a 1495-pound drop hammer using a drop of from 8 feet to 25 feet, a wooden cap protecting the head of the pile. Jetting was attempted but was not found to be successful. The appearance of these

piles indicates that they are in good condition and that apparently no defects have developed. There are no soft spots, nor is any erosion apparent; the reinforcement is undoubtedly in good condition."

"Poured in Place Cylinders or Piers, Governor's Landing. Square piers, 18 inches square, placed in 1918. The concrete was hand mixed and the bottom concrete deposited in paper; following sections were deposited dry or slightly dampened, letting the salt water mix in the concrete; above the level of the water, fresh water was used in the mix. The piers rest on rock on the coral reef; their length to low water is 12 feet, to high water 3.6 feet additional, and they project about 3 feet above high water. The materials used were the same as described above under precast piles, and ½ inch twisted square bars were used for reinforcing. The mix was 1:2:4, and shows a good surface except where the dry mix was deposited, which is rough and porous-looking in spots. Wooden forms were used, 1 x 12 surfaced and put together with tongue and groove. All pouring below water level was done continuously; construction joints were all above the water. Surfaces of joints were cleaned off before new concrete was deposited. Forms remained for ten days before being removed. The piers show good surface except as noted; the appearance between high and low water is fair. No serious defects have been noted."

"Decks and Superstructures. Deck on Governor's Landing is of the beam and girder type. It is uncovered, about 3 feet above high water, and exposed to much spray but to little or no wave action. The concrete and reinforcing materials are the same as those used in the piers. Forms were removed after 4 days. The main part of the superstructure is in good or fair condition, except that cracks and spalling occur in all the small sections such as rails and posts (ornamental lamp posts), due undoubtedly to the fact that there is only about ½ or ¾ inch of concrete between the outer surface and the reinforcing steel. The walls between piles at the Customs Wharf are hung and extend to just below low water. Concrete materials and reinforcing are the same here as in the piers and piles. The forms were 1 x 12 and had a bottom board, the under part of the wall being later filled in with stones. The concrete was placed dampened, and the forms removed after 4 days. The appearance is good."

"Methods of Protecting Concrete Structures. No particular precautions were taken in mixing and placing concrete aside from the procedure discussed above. No waterproofing was done. Concrete superstructures were washed with a cement wash containing 3 parts cement to one part lime."

There are timber wharves on concrete piles, concrete wharves on concrete cylinders, concrete sea walls and concrete retaining walls at Cavite and Olongapo, Philippine Islands, but unfortunately the records of materials and methods employed in their construction are incomplete.

In general, precast piles were well reinforced, with a covering of 1¼ to 2 inches thick, and vary in size from about 10 inches to 16 inches square. Cement of several standard brands and usually a good grade of crushed stone or screened and washed river gravel made up the aggregate, and the water for gaging was practically pure, either from mountain streams or artesian wells. The concrete was mixed to a fairly wet consistency in the proportion 1:1½:3, and the piles were brushed down with a cement wash after casting. The piles were cured for thirty days and driven with an ordinary drop hammer of from 1500 to 2600 pounds weight.

The precast concrete cylinders for the two concrete wharves at Olongapo installed in 1909, are 2 feet 6 inches in diameter at the top, with a flared base 4 feet 6 inches in diameter. The precast shells are reinforced with plain 1-inch rods vertically, and ½-inch plain rods horizontally. The materials and methods were the same as for the precast piles. The proportions of the mix are unknown.

The cylinders supporting the Coaling Plant Wharf at Cavite, built in 1903, were poured in place inside of heavy cast iron cylinders. The mixing

materials, conditions, etc., are not recorded, but are believed to have been uniformly good.

The girders and beams of the three concrete wharves at Olongapo are structural steel encased in concrete. The decks of these wharves are concrete, reinforced. The abutment for the two concrete wharves at the Olongapo Navy Yard is reinforced concrete of quite simple design and construction. The wall supporting the inner side of the Olongapo Coaling Plant Wharf is 18 feet high with a 9 foot base. Its face is battered 1 foot in 4 feet, and its back is stepped off one foot at points four and eight feet down from the top. The concrete for this wall is 1:2:4 below M. L. W. and 1:3:6 above that point. Its face above M. L. W. is composed of 1:2 cement mortar finish, placed by spading back the concrete from the front of the form as the work progressed.

Concrete sea walls, of several types, exist at the Cavite and Olongapo Naval Stations, but as all of them are of simple design and construction and are erected in only two or three feet depth of water they are of but little interest. No data concerning the construction of the wall along the inner face of the wharf at the Coaling Plant, Cavite, are available.

So far as a superficial examination can reveal, these structures appear to be in good condition as a whole.

Metal

With reference to metal structures, the Pago Pago harbor report states as follows:

> "Piles and Cylinders. The Station Wharf is a steel wharf with a wooden deck. The piles are 6 and 8 inches in diameter, solid steel, driven with a drop hammer in some cases, screwed in others, and in still other cases large cast steel discs, notched into the pile, rest on rock fill on the coral reef, these discs constituting the bearing surface of the pile. The work was done in 1899 and 1900. The piles are exposed to water a length of from 0 to 25 feet; further a distance of 3.6 feet for range of tide, while the wharf is about 8 feet above high water. The piles show no serious deterioration; no electrolytic action has been noticed, although such action is supposed to have taken place at times in the past when copper sheathed vessels have been alongside. There is a good deal of growth and incrustation of barnacles on the piles, but the rusting is only surface rusting, no spalling or other defects having been observed to date."
>
> "Girders, Trusses, Beams, etc. The superstructure of the Station Wharf is built of lattice girders, I-beams, struts, hangers, and eye-bars, square, with turnbuckles. The pile caps are cast iron. Practically all of this material is in very poor condition, except that which was renewed in 1918. It is exposed to spray, but little or no wave action. The paint is red lead (1918); it has not been chipped or painted within the last four years, due to lack of funds."
>
> "Miscellaneous Metal Structures and Parts: Buoys and chain. The condition below water is good; generally covered with barnacles and growth. The buoys are worn thin near the water line, and somewhat deteriorated above. They are located in the Bay and are exposed to a little wave action and much sun, wind and spray. The material is Navy standard."
>
> "Methods of Protecting. Material conforms to Navy specifications. The buoys are painted every 6 months; the Wharf has not been painted for 4 years. No other coverings are used."

Metal piles support the front edge of the Coaling Plant Wharf, Cavite. These piles consist of cast iron sections, 12½ inches outside diameter, length per section, 12 feet ½-inch to 12 feet 6½ inches, with bell joints 12 inches deep, pinned together, assembled so as to give a total net length of

approximately 70 feet. The lower (or point) section has an overall length of 4 feet (net 3 feet) and has no bell, a shoulder being provided to serve the same purpose as a bell. These piles are reinforced with 60 pound R. R. rails and were filled with rich concrete, the exact proportions of which are unknown. The cast iron is 1¼ inches thick. They were driven in 1903, coated with some kind of bituminous compound and appear, from a superficial examination, to be in good condition.

Field Experiments

Experiments with the method of protecting piles with steel and copper roofing nails are being conducted by the Navy at Pearl Harbor. The tests are so arranged as to afford a comparison of results with different spacings of nails and untreated woods, and each group includes five test pieces which are to be removed at periods of ½, 1, 2, 5 and 10 years after date of installation, September, 1923.

Coating with copper paint is a process used to protect wood spar buoys, but as they are renewed practically every 6 months, the ultimate protective quality of this paint in this district is not known.

Conclusions

Both molluscan and crustacean borers are very active in all these harbors, and the best possible protection is needed for timber piles. In Cavite the predominance of *Martesia* indicates the necessity for mechanical protection.

The age of the concrete structures reported is not great enough to permit drawing conclusions as to the life of this material.

The record of the steel piles at Tutuila is good and should encourage the consideration of this material.

CHAPTER XI

BIBLIOGRAPHY

The Committee wishes to offer its acknowledgments for many titles for the sections on Biology and Wood Preservation to Dr. C. A. Kofoid of the University of California and Dr. A. L. Barrows, Asst. Secretary, National Research Council. Other titles have been incorporated from the very exhaustive bibliographies assembled by Dr. Frederick Moll and published in "Naturwissenschaftliche Zeitschrift für Forst und Landwirtschaft," Vol. 12, pp. 505-564 (Nov.-Dec. 1914) and Vol. 13, pp. 178-207, (Apr.-May, 1915).

Acknowledgment is also made to Mr. Duff A. Abrams of the Portland Cement Association and Lewis Institute for a large number of titles in the section on Cement and Concrete in Sea Water and to members of the Engineering Societies Library staff for their work of checking and revising the manuscript of the wood preservation, cement and concrete in sea water, metal and miscellaneous sections.

MARINE BORERS—BIOLOGICAL

GENERAL AND MOLLUSCA

Adanson, Michel
1759—Description d'une nouvelle espèce de ver qui ronge les bois et les vaisseaux observée en Sénégal. Acad sci Paris Hist p 249-78, pls.

Akademie van Wetenschappen, Amsterdam.
1860-9—Verslag over den paalworm, uitgegeven door de natuurkundige afdeeling der K. Akademie van Wetenschappen, Amsterdam. 158 p, 4 pls, 4 tabs. Succeeding reports published in K Akad Wetenschappen, Afd Nat Verslagen en Meded v 10 (1860) p 162-4; v 12 (1861) p 133-50; v 13 (1862) p 318-29; v 15 (1863) p 293-310; v 17 (1865) p 74-111; s 2, v 1 (1866) p 157-80; v 3 (1869) p 207-30.

Alder, Joshua, & **Hancock,** Albany.
1851—On the branchial currents in *Pholas* and *Mya*. Ann Nat Hist s 2, v 8, p 370-8, pl xv figs 1-3. Abst in Brit Assoc Adv Sci Rept, 21st meeting, Trans of sections p 74-5: Ann Sci Nat s 3, v 15 (Zool) p 380-1.

Aldrovandi, Ulisse.
1602—De animalibus insectis libri septem cum singulorum iconibus ad vivum expressis. 1st ed. Bologna. x, 767, 43 p, figs.

Atwood, William G.
1922—Marine borers. Am Soc Civil Eng Proc v 48, p 1408-24, 7 figs.

1923—Mollusk borer attacks concrete pile protection. Ry Rev v 72, p 690-4.

1923—Report of Committee on marine piling investigations of the National Research Council in cooperation with the Committee on wood preservation, American Railway Engineering Association. Am Ry Eng Assoc Bull 255, p 965-1022, figs 1-4 & 14 figs in text, 1 map.

Aucapitaine, Henri.
1851—Note sur les moyens qu'emploient les pholades pour creuser les roches. Acad sci Paris, Compt rend v 33, p 661.

1851—Observations sur la perforation des roches par les mollusques du genre *Pholas*. Rev & mag zool s 2, v 3, p 486-8.

1853—Note sur la perforation des roches par les mollusques du genre *Pholas*. Soc géol France Bull s 2, v 10, p 389-92.

1854—Observations sur les mollusques perforants. Ann sci nat s 4, v 2 (Zool) p 367-72.

1860—Nouvelle observation sur la perforation des roches par certains mollusques acéphales. Acad sci Paris, Compt rend v 50, p 95-7.

Barrois, T.
1889-90—Le stylet crystallin des lamellibranches. Rev biol nord France v 1, p 124-41, 161-9, 263-71, pls iii-v, 3 figs; v 2, p 209-26, 299-311, 351-7, pls iii-v.

Barrows, A. L.
1917—An unusual extension of the distribution of the shipworm in San Francisco Bay, California. Univ Calif Publ Zool v 18, no 2, p 27-43. Abst in Eng News Rec v 85, p 949.

Bartsch, Paul.
1915—Report on the Turton collection of South African marine mollusks, with additional notes on the South

African shells contained in the United States National Museum. U S Nat Mus Bull v 91, p 1-305, pls i-liv.

1916—A new *Teredo* from the west coast of America. Nautilus v 30, p 47-8.

1920—A new shipworm. Biol Soc Washington Proc v 33, p 69-70.

1921—A new classification of the shipworms and descriptions of some new wood boring mollusks. Biol Soc Washington Proc v 34, p 25-32.

1922—A monograph of the American shipworms. U S Nat Mus Bull 122, p 1-51, pls 1-37, 1 fig.

1923—Additions to our knowledge of shipworms. Biol Soc Washington Proc v 36, p 95-102.

1923—Stenomorph, a new term in taxonomy. Science n s v 57, p 330.

1923—Status of *Teredo beachi* and *Teredo navalis*. Science n s v 57, p 692.

Baster, Job.
1739—Dissertation on the worms which destroy the piles on the coast of Holland and Zealand. Phil Trans v 41, p 276-88, pl ii.

1759-65—Opuscula subseciva, observationes miscellaneas de animalculis et plantis quibusdam marinis eorumque ovariis et seminibus continentia. Harlem 2 v, fig.

Bate, Spence.
1849—Notes on boring mollusca. Brit Assoc Adv Sci Rept 19th Meeting, p 73-5, 115-7. Abstract only. Original ms with water-colour drawings in Natural History Dept of the Brit Mus.

Baumhauer, E. H. von.
1866—Sur le taret et les moyens de préserver le bois de ses dégâts. Arch Néerland sci v 1, p 1-45, 4 pls; Ann Sci Nat v 6 (Zool), p 112-51.

1869—Sur le moyens de préserver le bois des attaques du taret. Arch Néerland sci v 4, p 160-6.

1878—The *Teredo* and its depredations. Pop Sci Mo v 13, p 400-10, 11 figs, p 545-58, 4 figs.

Bayley, G. W. R.
1875—The *Teredo navalis*, or shipworm. Am Soc Civil Eng Trans v 3, p 155-69.

Bergen, C. A. von.
1760—Classes conchyliorum. Nurimburg. 132 p.

Bernard, F.
1897—Quatrième et dernière note sur la développement et la morphologie de la coquille chez les lamellibranches. Soc géol France Bull v 25, p 559-66.

Beuk, S.
1899—Zur kenntniss des baues der niere und der morphologie von *Teredo* L. Zool Inst Wien Arb v 11, 269-88, pls 24-6.

Blum, Harold F.
1922—On the effect of low salinity on *Teredo navalis*. Univ Calif Publ Zool v 22, no 4, p 349-68, 4 figs.

Borley, J. O.
1909—Notes on British marine boring organisms. Roy commission on coast erosion & afforestation v 2, pt 2, app no xxix, p 1-3.

Bouchard-Chantereaux.
1879—Observations sur divers mollusques marine du Boulonnais. J conchyl v 27, p 122-5.

Brogger, W. C.
1872—Bidrag til Kristianiafjordens molluskfauna. Christiania. 86 p, 1 col pl.

1873—(Same) Nyt Mag Naturvid v 19, p 103-45.

Brookes, Samuel.
1815—An introduction to the study of conchology: including observations on the Linnaean genera, and on the arrangement of M. Lamarck, a glossary, and a table of English names. London. vii, 164 p, 11 pls.

Brown, A. W.
1911—Notes on the breeding and the boring habits of *Pholas crispata*. Zoologist, London v 15, p 437-40.

Buonanni, Filippo.
1684—Recreatio mentis et oculi in observatione animalium testaceorum Rome. xvi, 270 p, 139 pls.

Burrow, E. I.
1818—Elements of conchology, 2d ed. London. xxiii, 245 p, 28 pls.

Cailliaud, Frédéric.
1846—Traces d'animaux perforants dans un porphyre-roche protogynique, en Belgique. Soc géol France, Bull s 2, v 3, p 25-7.

1850—Nouvelles observations au sujet de la perforation des pierres par les mollusques. J conchyl v 1, p 363-9.

1851—Nouveau fait relatif à la perforation des pierres par les pholades. Acad sci Paris, Compt rend v 33, p 572-3. Abst in Am J Sci & Arts s 2, v 13, p 287.

1852—Note sur un nouveau fait relatif à la perforation des pierres par les pholades. Soc géol France Bull s 2, v 9, p 87-8.

1852—Réponse à une question de priorité soulevée par J. Robertson, relativement aux moyens employés par les pholades pour percer les pierres. (Lettre de M. Cailliaud) Acad sci Paris, Compt rend v 34, p 190-1.

1853—Gneiss perforés par des pholades de la Loire inférieure. Soc géol France Bull s 2, v 10, p 314.

1854—Observations et nouveaux faits sur les mollusques perforants. Acad sci Paris, Compt rend v 39, p 34-6.

1857—Procédé employé par les pholades dans leur perforation, suppl. Rev & Mag zool v 9, p 64-73.

1857—Des tarets et autres perforants. J conchyl v 2, p 102-3, 130-7.

Calman, W. T.
1919—Marine boring animals injurious to submerged structures. Brit Mus Nat Hist, Econ Ser no 10, 35 p, 21 figs.

1920—On marine boring animals. *In* Inst of civil eng, London, Deterioration of structures in sea-water, 1st Rept, p 63-78, pl 1.

1920—Notes on marine wood-boring animals. I The shipworms (Tere-

dinidae). Zool Soc London Proc p 391-403, text-figs 1-11.

Carpenter, Philip P.
1865—Diagnoses of new forms of mollusca from the Vancouver district: *Terebratula unguicula, Nettastomella Darwinii* Sby, *Darina declivis, Saxidomus brevisiphonatus.* Zool Soc London Proc p 201-4.

Chemnitz, Joh. Hieron.
1775-6—Von der verwahrungsmethode der Danischen schiffer wider die verwüstungen der pfahlwürmer. Ges Naturfors Freunde Berlin Beschäftgn v 1 (1775) p 426; v 2 (1776) p 560.

Christian, E. S.
1915—Destruction of timber by marine borers. Ry Age v 58, p 162-3.

Clapp, W. F.
1923—A new species of *Teredo* from Florida (*Teredo bartschi*) Boston Soc Nat Hist Proc v 37, no 2, p 31-8, 1 fig, pls 3-4.
1924—New species of shipworms in Bermuda. Am Acad Arts Sci Proc v 59, no 12, p 279-94, pls 1-3, 1 fig.

Clark, William.
1850—On the terebrating mollusca. Ann & Mag Nat Hist s 2, v 5, p 6-14.
1850—On the Pholadidae. Ann & Mag Nat Hist s 2, v 6, p 313-6.

Clessin, Stephan.
1893—Die familie Pholadea. *In* Martini, F. H, W. and Chemnitz, J. H. Systematisches conchylien cabinet, v 11, pt 4, 88 p, 21 col pl.

Collins, P.
1915—Burrowing animals: borers that wend their way even through rock. Sci Am v 113, p 99, 113, 10 figs.

Colgan, Nathaniel.
1908—The shipworm and wood-boring crustaceans in Kingstown harbour. Irish Nat, Dublin v 17, p 9-14.

Conrad, Timothy A.
1850-4—Synopsis of the genera *Parapholas* and *Penicilla.* Acad Nat Sci, Philadelphia, J v 2, p 335.
1862—Monograph of the Pholadacea. Am J Conch v 3, no 3, app.

Coquand, H.
1838—Calcaire du terrain gypseux d'aix perforé par les pholades: conséquences. Soc géol France Bull s 1, v 9, p 219-20.

Costa, Emanuel Mendez da.
1778—Historia naturalis testaceorum Britanniae, or the British Conchology. London. xii, 254, vii p, 17 col pls.

Coupin, Henri.
1893—Sur l'élimination des matières étrangères chez les acéphales et, en particulier, chez les pholades. Acad sci Paris, Compt rend v 117, p 373-6. Abst in Rev sci v 52, p 379; Roy Micros Soc J s 2, v 13, p 731.
1900—Sur les fonctions de la tige cristalline des acéphales. Acad sci Paris, Compt rend v 130, p 1214-6.

Cunningham, Joseph T.
1911—Teredo. Encyc Brit, 11th ed, p 637-9, 1 fig.

Dall, W. H.
1889—Notes on the anatomy of *Pholas costata* and *Zirphaea crispata.* Acad Nat Sci, Philadelphia Proc p 274-6.

Dalyell, John G.
1851-8—The powers of the Creator displayed in the creation; or observations on life amidst the various forms of the humbler tribes of animated nature with practical comments and illustrations. London. 3 v, 145 col pls.

Dampier, William.
1698—A new voyage round the world. 3d ed corrected. London. 2 v.

DeKay, James E.
1843-4—Natural history of the State of New York. Zoology. Mollusca pt 5, p 249.

Deshayes, G. P.
1836-49—Les mollusques. *In* Cuvier, G. L. Le règne animal pt 5. 3d ed. text 1 v, atlas 1 v in 2.
1839—Mémoire sur la famille des pholadaires. Ann sci nat s 2, v 11 (Zool) p 240-74.
1845-8—Histoire naturelle des mollusques. v 1 Mollusques acéphales. *In* Explor sci Algérie xx, 609 p, atlas 160 p, 143 pls.
1846—Mémoire sur l'organisation des animaux de genre taret. Acad sci Paris Compt rend v 22, p 298-301.
1846—Ueber die organization der gattung *Teredo.* N Notiz Geb Nat Heilk, Froriep's v 37, p 320-4.
1850—Quelques observations au sujet de la perforation des pierres par les mollusques. J conchyl v 1, p 22-34.

Deslandes.
1720—Sur les vers qui rongent le bois des vaisseaux. Acad sci Paris Hist (1720), p 26, 29; also *In* his Recueil de differens traités de physique et d'histoire naturelle. Paris (1736). v 1, p 214.

Dillwyn, L. W.
1817—A descriptive catalogue of recent shells, arranged according to the Linnaean method. London. 2 v in 1, xii, 1092 p.

Donovan, Edw.
1799-1804—Natural history of the British shells. London. 5 v in 3.

Dore, Walter H., & **Miller,** R. C.
1923—The digestion of wood by *Teredo navalis.* Univ Calif Publ Zool v 22, no 1, p 383-400, pl 18.

Dubois, R.
1889—Remarques sur la physiologie et l'anatomie du siphon du *Pholas dactylus.* Soc biol Paris Compt rend s 9, v 1, p 521-3.
1890—Étude sur la nature des valves ou pièces accessoires chez les pholades et sur l'importance que présente la connaissance de leur texture histologique au point de vue de la classification. Soc Malacol France Bull v 7, p 349-58.

1892—Anatomie et physiologie comparées de la pholade dactyle: structure avec une théorie générale des sensations. Univ Lyons Ann v 2, no 2, x, 167 p, 15 pls. figs.

Dupetit-Thouars, L. M. A.
1859—Sur les tarets et les coquilles lithodomes. Acad sci Paris Compt rend v 48, p 545-6.

Durand, W. F.
1887—Internal parasites of *Teredo navalis*.. Am Micros J v 8, p 224-6.

Elliott, W. T., & **Lindsay**, P.
1911—Remarks on some of the boring mollusca. Brit Assoc Adv Sci Rept, 81st Meeting, p 433.

Embree, C. J.
1922—Greenheart as *Teredo* resistant on Panama locks. Eng News v 89, p 619-21, 3 figs. Discussion p 626, 714.

Fabricius, O.
1798—Tillaeg til conchylieslaegterne *Pholas*, *Mya* and *Solen*. Naturhist Selskab Kiobenhavn Skrivt v 4, pt 2, p 34-51, pl 10.

Faucette, W. D.
1911—Marine wood destroyers in the waters of the South Atlantic ports. Eng News v 65, no 1, p 12-3.

Fischer, Paul.
1853—Études sur le taret noir (*Teredo nigra*). Soc Linn Bordeaux Actes v 19, p 391-404, pls 1 and 2.

1858—Études sur les pholades. J conchyl v 7, p 47-58, 169-78, 242-53. Liste monographique des espèces du genre taret. J conchyl s 2, v 8, p 129-44, 254-60.

Fleuriau de Bellevue.
1802—Mémoire sur quelques nouveaux genres de mollusques et de vers lithophages, et sur la faculté qu'ont ces animaux de percer les rochers. J phys v 54, p 345-55.

Forbes, Edward, & **Hanley**, Sylvanus.
1848-50—History of British mollusca and their shells. London. v 1.

Frey, Heinrich, & **Leuckart**, C. G.
1847—Beiträge zur kenntniss wirbelloser thiere mit besonderer berücksichtigung der fauna des norddeutschen meeres. Braunschweig. 170 p, 2 pls.

Gardner, J. S.
1886—Does *Teredo* inhabit fresh water? Geol Mag s 3, v 3, p 336.

Gardner, Henry A.
1922—Modern research on anti-fouling paints. Paint Mfrs Assoc U S Tech Circ no 157, p 35-72, 23 figs.

1923—Marine borer paints. Paint Mfrs Assoc U S Tech Circ no 176, p 207-19, figs 1-8.

Garner, Robert.
1836—On the anatomy of the lamillibranchiate conchiferous animals. Zool Soc London Proc v 4, p 12-6.

1838—(Same) Mag Nat Hist n s v 2, p 578-83.

1839—(Same) Mag Nat Hist n s v 3, p 123-9, 164-71, 294-304, 439-44.

Gatliff, J. H. & **Gabriel**, C. J.
1915—Notes on some Victorian species of *Teredo*. Roy Soc Victoria Melbourne Proc n s v 28, p 115-23, pls xii-xiii.

Geyer, D.
1909—Die weichthiere Deutschlands. Stuttgart. viii, 116 p, 3 pls, 60 figs.

Gould, A. A.
1840-1—Results of an examination of the shells of Massachusetts and their geographical distribution. Boston J Nat Hist v 3, p 483-94.

1846—[Note on *Pholas costata* and *Pholas truncata*]. Bost Soc Nat Hist Proc v 2, p 81-2.

1870—Report on the invertebrata of Massachusetts. 2d ed, comprising the Mollusca, ed by W. G. Binney. Boston. v, 524 p, pls xvi-xxvii, figs 350-755.

Gray, John Edward.
1825—Observations on the structure of the pholades. Zool J v 1, p 406-9.

1827—A monograph of the genus *Teredo* of Linné, with descriptive characters of the species in the British Museum. Phil Mag s 2, v 2, p 409-11.

1833—Some observations on the economy of molluscan animals, and on the structure of their shells. Phil Trans v 123, p 771-819.

1838—On the boring of pholades. Brit Assoc Adv Sci Rept, 8th Meeting, Trans Sects, p 111-2.

1851—An attempt to arrange the species of the family Pholadidae into natural groups. Ann Nat Hist s 2, v 8, p 380-6.

1855—On the anomalous oyster shell (*Pholas candida*) described in the "Annals" for February. Ann Nat Hist s 2, v 15, p 210-1.

1857—Observations on the genus *Furcella* Oken, a conchifer without concha or normal valves, and on the genera *Teredo* and *Chaena*. Zool Soc London Proc v 25, p 243-8, pl xxxix.

1858—On the structure and position of the genus *Teredina* Lamarck. Ann Nat Hist s 3, v 2, p 85-90, 162-3, 1 fig.

1861—On a large species of *Teredo*, supposed to be the animal of the genus *Furcella* Lamarck. Zool Soc London Proc p 313-4.

Griffiths, J.
1806—Description of a rare species of worm shells, discovered at an island lying off the north-west coast of the Island of Sumatra in the East Indies. Phil Trans v 96, p 269-75, pls x-xi.

Hancock, Albany.
1845—Note on the boring apparatus of the carnivorous gasteropods and of the stone and wood burrowing bivalves. Ann & Mag Nat Hist v 15, p 113-4; also Am J Sci & Arts s 2, v 1, p 130-1 (1846).

1848—On the boring of the Mollusca into rocks, etc., and on the removal of portions of their shells. Ann & Mag Nat Hist s 2, v 2, p 225-48, pl 8, figs 1-7. German trans in N Notiz Geb Nat Heilk, Froriep's v 11, col 83-9, 97-102; Arch Naturgeschichte, Wiegmann's v 15, p 1-17, col 253-67.

1849—Über die weise, in welcher mollusken die felsen anboren und ihre eigenen schalen abscheisen. N Notiz Geb Nat Heilk, Froriep's v 11, col 83-9, 97-102.

1860—On the occurrence of *Teredo* and *Xylophaga dorsalis* on the Durham coast. Tyneside Nat Field Club Trans v 4, p 68-9.

Hanley, Sylvanus.

1885—On the *Teredo utriculus* of Gmelin, with remarks upon other shipworms. Ann & Mag Nat Hist s 5, v 16, p 25-31.

Harrington, C. R.

1921—A note on the physiology of the shipworm (*Teredo norvegica*) Biochem J v 15, no 6, p 736-41, fig.

1922—Report of work done at the Marine Biological station, Plymouth, July 1st to September 18th, 1920. *In* Inst Civil Eng, London, Deterioration of structures in sea water, 2d Rept, p 35-43.

Harting.

1860—Remarques sur la manière dont les tarets perforent le bois. Ann sci nat s 4, v 14 (Zool) p 127-8.

Hatschek, B.

1880—Ueber entwicklungsgeschichte von *Teredo*. Univ Vienna, Zool Inst Arb v 3, no 1, 44 p, 3 col pls.

Hedley, Charles.

1893—*Pholas obturamentum*, an undescribed bivalve from Sydney harbour. Australian Mus Sydney, Records v 2. p 55-7, 1 pl.

1895—Conchological notes. Linnean Soc N S Wales Proc v 9, p 464-6, figs.

1895—Notes on Australian shipworms. Linnean Soc N S Wales Proc v 9, p 501-5.

1896-1900—The Mollusca of Funafuti. pt 2 Pelecypoda and Brachiopoda (1899). Australian Mus Sydney Mem v 3, p 489-510, figs.

1898—Further notes on Australasian shipworms. Linnean Soc N S Wales Proc v 23, p 91-6, figs.

1897-1900—A shipworm new to Australia (1899). Australian Mus Sydney, Records v 3, p 134.

1901—The marine wood borers of Australasia and their work. Australian Assoc Adv Sci, 8th meeting Rept (1900), p 237-55, pls vii-x.

Hobby, A. S.

1918—Marine wood borers work in deep water. Eng News v 81, p 551-2, 2 figs. Discussion p 772-3.

Home, Everard.

1814-23—Lectures on comparative anatomy. London. v 4 (1823), Lecture 6, pls xli-xliii.

1806—On the shell of the sea worm found on the coast of Sumatra, proving it to belong to a species of *Teredo*, with an account of the anatomy of the *Teredo navalis*. Phil Trans v 96, p 276-92, pls xii-xiii.

Hutton, F. W.

1873—Catalog of the marine Mollusca of New Zealand, with diagnoses of the species. Wellington, xx, 116 p, 1 pl.

Hutton, W. Harrison.

1911—The boring habits, etc. of the *Pholas*. Naturalist, London p 423-4.

1913—The boring habits of the *Pholas*. Naturalist, London p 229.

Institution of civil engineers, London.

1920—The deterioration of structures of timber, metal and concrete exposed to the action of sea water. 1st Rept of the committee, ed by P. M. Crosthwaite & Gilbert R. Redgrave, London. x, 11-301 p, 37 figs, 33 pls.

1922—Deterioration of structures in seawater 2d (interim) rept. 57 p, 6 figs.

1923—(Same) 3d (interim) rept. vi, 79 p, 11 pls.

Irving, John.

1912—On the boring habits of the *Pholas*. Naturalist, London p 45-6.

Jarvis, J.

1856—On the *Teredo* or salt-water worm. Nat Inst Washington Proc n s v 1, no 2, p 60-7.

Jeffreys, John Gwyn.

1860—On the British teredines or shipworms. Brit Assoc Adv Sci Rept 30th Meeting Trans Sects, p 117-9.

1860—A synoptical list of the British species of *Teredo*, with a notice of the exotic species. Ann Nat Hist s 3, v 6, p 121-7.

1860—Notice of an undescribed peculiarity in *Teredo*. Ann Mag Nat Hist s 3, v 6, p 289-91.

1861—Preliminary report on the best mode of preventing the ravages of *Teredo* and other animals in our ships and harbours. Brit Assoc Adv Sci, 31st meeting Rept p 200.

1869—British conchology. London. v 5, p 193-4, pls lii-liv.

Jehu, T. J.

1918—Rock - boring organisms as agents in coast erosion. Scot Geog Mag v 34, p 1-11.

Johnson, Charles W.

1905—On the species of *Martesia* of the eastern United States. Nautilus v 18, p 100-3, figs 1-3.

1905—Further notes on the species of *Martesia* of the eastern coast of the United States. Nautilus v 18, p 112-3.

Jousseaume, Félix.

1891—Coquilles nouvelles (*Martesia roseotincta* and *Solen digitalis*). Le Naturaliste v 13, p 183.

Kamiya, S.

1918—Funakin-mushi ni tsuite (On timber-boring molluscs). Dobuts Zasshi Tokyo v 30, p 116-9, 165-9.

Keer, P. M.

1903—Beitrag zur kenntnis der schiffsbohrwurmes. Leiden. 58 p, 4 pls.

Kellogg, J. L.

1915—Ciliary mechanisms of lamellibranchs with descriptions of anatomy. J Morphology v 26, p 625-701, 72 figs.

Kindle, E. M.

1918—Notes on the habits and distribution of *Teredo navalis* on the Atlantic coast of Canada. Contr Canadian Biol 1917, no 38a, p 92-103.

Kofoid, C. A.
1921—The marine borers of the San Francisco Bay region. *In* San Francisco Bay Marine Piling Surv, Rept v 1, Biol Phase p 23-61, pls 1-36, 1 fig, 1 map; also Am Wood Preservers' Assoc Proc v 17, p 209-47, pls 1-36, 1 map.

Kofoid, C. A. & **Miller,** R. C.
1922—Biological section of 2d annual progress report. San Francisco Bay Marine Piling Surv v 2, p 72-82, pls 1-16; also Am Wood Preservers' Assoc v 18, p 350-61, pls 1-16.
1923—Biological section of 3d annual progress report. San Francisco Bay Marine Piling Surv v 3, p 40-52, pls 1-6, 1 map.
1923—Rock boring mollusks attack concrete pile jackets. Eng News Rec v 90, p 499-500, 1 fig. Discussion p 635-6, 1 fig, p 894.

Kooy, C.
1922—[Suggests foreign woods to resist borers.] Eng News Rec v 89, p 626. Discussion p 714.

Kuhlman, E.
1914—Über das bohren der muscheln. Prometheus v 25, p 360-63.

Kuhlman, W.
1916—Der bohrapparat des bohrwurms *Teredo navalis.* Naturwis v 4, p 710-3.

Lamarck, J. B.
1815-22—Histoire naturelle des animaux sans vertèbres. Paris. v 5 (1818).

Lamy, Edouard.
1922—Notes sur les espèces lamarckiennes de *Teredo* (taret). Mus hist Nat Paris Bull p 177-81.

Latreille, P. Andre.
1824—Esquisse d'une distribution générale des mollusques, d'après un ouvrage inédit, intitulé: "Familles naturelles du règne animal, exposées succinctement et dans un ordre analytique, avec l'indication de leurs genres. Ann sci nat v 3, p 317-35, 1 chart; also N Notiz Geb Nat Heilk, Froriep's v 10 (1825) col 161-6.

Laurent, J. L. Maur.
1848—[Expérience concernant les animaux nuisibles aux bois de construction (tarets).] Soc philomat Proc verb p 54-5.
1848—[Remarques sur les tarets.] Soc philomat Proc verb p 38-9.
1850—Recherches sur les moeurs des tarets. J conchyl v 1, p 250-76, 329-63.
1850—Recherches et résultats d'observations de moeurs des animaux nuisibles aux grands approvisionnements de bois de marine (Extrait par l'auteur). Acad sci Paris Compt rend v 31, p 74-8.

Lazier, Edgar L.
1924—Morphology of the digestive tract of *Teredo navalis.* Univ Calif Publ Zool v 22, no 14, p 455-74.

Lehmann.
1840—Om *Teredo navalis* og et naturligt vaern imod summe. Forhandl Skandin Naturf v 2, p 291-4.
1843—Ueber den pfahlwurm. *Teredo navalis* und eine natürliche schutzwehr gegen denselben. Isis v 36, col 295-8.

Le Juge, Ed.
1869—Note sur les pholades. Roy Soc Arts & Sci Mauritius n s v 3, p 3, 9-11.

Lindsay, B.
1912—Some observations on boring Mollusca. Brit Assoc Adv Sci Rept 82nd Meeting. p 516.

Linné, Carl von.
1766-8—Systema naturae. 12th ed rev. Stockholm. v 1, pt 2 (1767).

Lister, Martin.
1678—Historiae animalium Angliae tres tractatus. London. 250 p, 9 pls.

Lloyd, Francis Ernest.
1896—On *Pholadidea penita* and its method of boring. Science n s v 4, p 188-90, figs.
1898—On the mechanisms in certain lamellibranch boring molluscs (1897). N Y Acad Sci Trans v 16, p 307-16, pls xxv-xxvi.

Lovén, S. L.
1846—Index molluscorum litora Scandinaviae occidentalia habitantium. K Vetenskaps-Akad forhandl Overs v 3, p 135-60, 183-204.

MacGillivray, P. H.
1845—On a species of *Teredo* (*T. subericola*) found in cork floats on the coast of Aberdeenshire. Edinb N Phil J v 38, p 138-41.

McGlone, R. G.
1914—*Teredo* in fresh water. Eng News Rec v 72, p 400.

McIntosh, W. C.
1874—On the invertebrate marine fauna and fishes of St. Andrew's. Sec 2, Mollusca (proper). Ann & Mag Nat Hist s 4, v 13, p 342-57.
1875—The marine invertebrates and fishes of St. Andrews. Edinburgh & London. vi, 186 p, 9 pls col.
1908—On the perforations of marine animals. Zoologist, London s 4, v 12, p 41-60.

Mark, E. L.
1924—Marine borers in Bermuda. Am Acad Arts Sci Proc v 59, no 11, p 259-76, pls i-iv, 5 figs.

Martens, E. von.
1900—Ein von pfahlwürmern (*Teredo*) durchlöchertes holzstück aus Togo. Ges Naturfors Freunde Berlin Sitzb p 180.

Ménégaux, Auguste.
1889—Histoire du taret. Naturaliste v 11, p 277-80, woodcut; also Roy Micros Soc J v 2, p 498.
1889—Sur les homologies de différents organes des tarets. Soc zool France Bull v 14, p 53-55; also Acad sci Paris Compt rend v 108, p 537-8.
1890—Recherches sur la circulation des lamellibranches marins. Besançon. 296 p, figs.

Menke, K. Th.
1830—Synopsis methodica molluscorum generum omnium et specierum earum, quae in Museo Menkeano adservantur, cum synonymia critica et

novarum specierum diagnosibus. Pyrmont. xvi, 168 p.

Meyer, Heinrich A., & **Möbius**, K. A.
1872—Fauna der Kieler bucht. v 2. Die prosobranchia und lamellibranchia. Leipzig. xxiv, 139 p, 22 pls col.

Miller, R. C.
1922—Variations in the shell of *Teredo navalis* in San Francisco Bay. Univ Calif Publ Zool v 22, no 2, p 293-328, pls 13-7, 6 figs.
1923—Variations in the pallets of *Teredo navalis* in San Francisco Bay. Univ Calif Publ Zool v 22, no 8, p 401-12, pl 19-20.
1924—Wood boring mollusks from the Hawaiian, Samoan and Phillipine Islands. Univ Publ Zool v 26, no 7,

Möbius, K.
1874—*Teredo navalis* in Kieler haven. Naturwis Ver Schleswig-Holstein Schrift v 1, p 36.

Moll, F.
1914—Die bohrmuschel (genus *Teredo* Linné) Naturwis Z Forst u. Landwirt v 12, p 505-64, 12 figs.

Montague, George.
1803-8—Testacea Britannica, or natural history of British shells, marine, land and fresh water. London. 2 v & suppl, figs col.

Moore, Edward.
1838—On the occurrence of the *Teredo navalis* and *Limnoria terebrans* in Plymouth harbour. Mag Nat Hist, Charlesworth's n s v 2, p 206-10; also N Notiz Geb Nat Heilk, Froriep's v 7, col 49-53.

Mörch, Otto A. L.
1871—Synopsis molluscorum marinorum Daniae. Naturhist Foren Videnskab Medd s 3, v 3, p 157-225.

Morse, E. S.
1919—Observations on living lamellibranchs of New England. Boston Soc Nat Hist Proc v 35, p 139-96, 48 figs.

Murphy, Martin.
1882—On the ravages of the *Teredo navalis* and *Limnoria lignorum* on piles and submerged timber in Nova Scotia and the means being adopted in other countries to prevent their attacks. Nova Scotian Inst Sci Proc & Trans v 5, p 357-76.
1895—Supplementary notes on the destroyers of submerged wood (1892). Nova Scotian Inst Sci Proc & Trans v 8, p 215-22.

Nakazawa, K.
1915—Funakuimushi ni tsuite no kansatsu (Observations on the ship borer *Xylotrya* sp.). Dobuts Zasshi Tokyo v 27, p 235-40.

Nelson, Thurlow C.
1918—On the origin, nature, and function of the crystalline style of lamellibranchs. J Morphology v 31, p 53-111, 17 figs.
1922—The European pileworm, a dangerous marine borer in Barnegat Bay, New Jersey. N J Agr Exp Sta Circ no 139, p 1-15, figs 1-8.
1923—Observations on marine borers in Barnegat Bay. N J Agr College Exp Sta 44th Ann Rept p 336-7.

Orton, J. H.
1914—Preliminary account of a contribution to an evaluation of the sea. Marine Biol Assoc U K, J v 10, p 312-26.

Osler, Edward.
1827—On the burrowing and boring marine animals. Phil Trans v 116, p 342-71, pls xiv-xv containing figs 1-10. Abst in Edinb J Sci v 6, p 270-4; also N Notiz Geb Nat Heilk, Froriep's v 17, col 289-92.

Parsons, James.
1748—Observations upon certain shellfish lodged in a large stone brought from Mahon harbour. Phil Trans v 45, no 485, p 44-8.
1765—An account of the *Pholas conoides*. Phil Trans v 55, p 1-6, pl 1.

Paton.
1850—Ueber die verwüstungen, welche der *Teredo navalis* und andere bohrwürmer anrichten. Tagsber Fortsch Nat & Heilk, Froriep's v 1, (Zool and Pal), no 188, col 252-3.

Payraudeau, B. C.
1826—Catalogue descriptif et méthodique des annelides et des mollusques de l'Ile de Corse. Paris. 7, 218 p, 8 col pls.

Pelseneer, P.
1891—Contribution à l'étude des lamellibranches. Arch biol v 11, p 147-312, 18 pls. Abst in Roy Micros Soc J v 11, p 582-4.
1897—Mollusques. *In* Blanchard, R. Traité de zoologie, sect xvi, 187 p, figs.

Pennant, Thomas.
1777—British Zoology. 4th ed. London. v 4, Crustacea, Mollusca, Testacea.

Philippi, R. A.
1853—Handbuch der conchyliologie und malacozoologie. Halle. xx, 547 p.

Poli, Giuseppe Saverio.
1791-1827—Testacea utriusque Siciliae eorumque historia et anatome. Parma, 3 v, atlas, 57 col pls.

Potts, F. A.
1920—Note on the growth of *Teredo navalis*. Carnegie Inst Washington Yearbook v 19, p 189, 197-8.
1923—The structure and function of the liver of *Teredo*, the shipworm. Cambridge Phil Soc Proc (Biol Sci) v 1, no 1, 17 p, 5 figs, pls I and II.

Quatrefages, Armand de.
1848—(Note sur les tarets.) L'Institut v 16, p 190-91.
1848—(Remarques relatives aux différentes espèces des tarets.) Soc philomat Proc verb p 43-44.
1848—Sur un moyen de mettre les approvisionnements de bois de la marine à l'abri de la piqûre des tarets. Acad sci Compt rend v 26, p 113-14.
1848—Note sur le développement de l'oeuf et de l'embryon chez les tarets. Ann sci nat s 3, v 9 (Zool), p 33-6; also Soc philomat Proc verb 1848, p 36-9; L'Institut v 16, no 750, p 149-50; abst in German in N Notiz Geb Nat Heilk, Froriep's s 3, v 7, col 51-3.

1849—Mémoire sur le genre taret (*Teredo*, Lin.) Ann sci nat s 3, v 11 (Zool) p 19-73, pls 1-2.

1849—Mémoire sur l'embryogénie des tarets. Ann sci nat s 3, v 11 (Zool), p 203-38, 9 pls, containing figs 1-36; abst in Acad sci Paris Compt rend v 28, p 430-3.

1850—Zur embryogenie des schiffsbohrers, *Teredo navalis*. Tagsber Fortsch Nat & Heilk, Froriep's v 1, no 1, col 6-8; no 7, col 9-12, tab 1, figs 26-41.

1850—Recherches expérimentales sur les spermatozoides des hermelles et des tarets. Ann sci nat s 3, v 13 (Zool), p 111-25; extract in Acad sci Paris Compt rend v 30, p 813-9.

1850—Expériences sur la fécondation artificielle des oeufs de hermelle et de taret. Ann sci nat s 3, v 13 (Zool), p 126-40; extract in Acad sci Paris Compt rend v 30, p 813-9.

Réaumur, R. A. F. de.
1712—Sur le mouvement progressif de quelques coquillages de mer, sur celuy des hérissons de mer, et sur celuy d'une espèce d'étoile. Acad Sci Paris Hist (1712), p 115-45, pls 6-8.

Récluz, C. A.
1847—Descriptions de plusieurs animaux mollusques bivalves, soit nouveaux, soit imparfaitement connu. Rev Zool v 10, p 336-43.

1849—Description de quelques nouvelles coquilles (*Teredo Petitii, Lutraia Senegalensis, Dreissena Sallei*) Rev & Mag Zool s 2, v 1, p 64-71.

Redgrave, Gilbert R.
1920—Abstract of references in the Proceedings of the Institution of Civil Engineers to the deterioration of structures and materials through sea-action. *In* Inst Civil Eng, London, Comm appointed to investigate the deterioration of structures of timber, etc. 1st Rept p 15-61.

Reeve, L.
1841—Conchologica systematica. London. 2 v.

Ripley, Charles M.
1909—Destructive marine woodborers. Sci Am Suppl v 67, no 1722, p 12, 4 figs.

Robertson, John.
1851—Note on the *Pholas dactylus*, or Sussex piddik: its boring power. Newman's Zool v 9, p 3175-6; also Edinb N Phil J v 51, p 194.

1852—Réclamation de priorité, adressée à l'occasion d'une communication récente de M Cailliaud, sur les moyens employés par les pholades pour percer les pierres. Acad sci Paris Compt rend v 34, p 60.

1853—Notice sur la perforation des pierres par le *Pholas dactylus*. J conchyl v 4, p 311-5.

Ross, John.
1859—The mode by which the *Pholas* bores. Newman's Zool v 17, p 6451-542.

Rousset de Missy, Jean.
1733—Observations sur l'origine, la constitution et la nature des vers de mer qui percent les vaisseaux, les piliers, les jetées, et les estacades. The Hague. 31 p, 2 pls.

San Francisco Bay Marine Piling Committee.
1921—Report on the San Francisco Bay marine piling survey. 104 p, 36 pl, 4 tabs, 5 figs, map; also Am Wood Preservers' Assoc Proc v 17, p 189-290, 36 pls, 4 tabs, 5 figs, map.

1922—Second annual progress report. 82 p, 16 pls, 2 diags; also Am Wood Preservers' Assoc Proc v 18, p 346-437, 16 pls, 2 diags.

1923—Third annual progress report. 409 p, 14 pls, 10 figs, 12 tabs; also Am Wood Preservers' Assoc Proc v 19, p 386-456, 11 figs, 12 tabs.

Schrenk, Hermann von.
1922—Destructive action of marine borers. Can Eng v 43, p 390-2; also (abbr) Eng and Contr v 58, p 47-50.

Schrenk, Hermann von, **Nelson**, Thurlow C., & **Taylor**, C. M.
1922—The marine borer problem in the vicinity of New York. Municip Eng J p 57-80, 7 figs.

Schröter, J. S.
1783-6—Einleitung in die konchylienkenntniss, nach Linné. Halle. 3 v, 9 pls.

Seba, Albert.
1743-65—Locupletissimi rerum naturalium thesauri accurata descriptio et iconibus artificiosissimis expressio per universam physices historiam. Amsterdam. v 3, p 39, 182, pls 16, 94.

Sellius, Godofredus.
1733—Historia naturalis Teredinis seu Xylophagi marini tubulo-conchoidis speciatim Belgici (Trajecti ad Rhenum). xxxiv, 353 p, 2 pls.

1733—Natuurkundige historie ven den zeehoutwerm, etc. Utrecht. pt 1, 303 p, fig.

Shackell, L. F.
1914—The comparative toxicity of coal-tar creosotes and creosote distillates and of individual constituents for the marine wood borer *Xylotrya*. Am Wood Preservers' Assoc Proc v 11, p 233-47, 9 figs.

1916—Marine borers from the wood preserver's standpoint: a description of experiments to determine the effects of various fractions of creosote on borers. Ry Age Gaz March 17.

Sigerfoos, Charles P.
1895-6—The Pholadidae. Johns Hopkins Univ Circ v 14, p 78-9, fig viii, (1894-5); v 15, p 87-9, 2 figs (1895-6); also Ann Nat Hist v 16, p 233-8; v 18, p 250-7. pt 1, Note on the early stages of development; pt 2, Note on the organization of the larva and the post-larval development of shipworms.

1898—Some notes on American shipworms. U S Bur Fisheries Bull v 17, p 189-91; also separately as Doc no 369.

1908—Natural history, organization and late development of the Teredinidae, or shipworms. U S Bur Fisheries Bull v 27, p 191-231, pl vii-xxi; also separately as Doc no 639.

Smeaton, John.
1791—A narrative of the building and a description of the construction of the Edystone lightouse with stone. London. Book 2, chap 2, par 79.

Smith, C. Stowell.
1908—Preservation of piling against marine wood borers. U S Forest Serv Circ no 128, p 1-15, figs 1-5.

Smith, Edgar A.
1903—On *Xylophaga praestans*, n sp. from the English coast. Malacol Soc London Proc v 5, p 328-30, figs.

Smith, Edgar A.
1884—(Mollusca of the Indo-Pacific.) Rept on the zoological collections made in the Indo-Pacific Ocean during the voyage of H M S Alert, 1881-2.

Smith, John.
1897—*Pholas crispata*, Linn, as a borer (1893). Glasgow Nat Hist Soc Proc & Trans v 4, p 37-9.

Snow, Charles H.
1898—Marine wood borers. Am Soc Civil Eng Trans v 40, p 178-214, pls 13-23, 4 figs. Rev & publ by N Y Univ School of Applied Sci, Oct 1908; also Am Soc Civil Eng Proc v 24, p 399-430, pls xxi-xxxi, 4 figs.

Sowerby, George B.
1839—Conchological manual. London. x, 130 p front. 488 col figs.
1849—On a new genus of Pholadidae, with notices of several new species and of a remarkable specimen of *Pholas calva* in Mr. Cuming's collection. Zool Soc London Proc v 17, p 160-2, pl v.

Spengler, Lorenz.
1788—Beskrivelse over en meget sielden sexskallet pholade tillige med Dyret fra den Siamske havbugt (1784). K Danske Videnskab Selskab Skrivt Nye Saml v 3, p 128-38, 1 pl.
1792—Betragtninger og anmaerkninger ved den Linneiske slaegt *Pholas*. Naturhist Selskab Kiobenhavn Skrivt v 2, p 73-106.

Stark, John.
1826—Observations on two species of *Pholas* found on the sea-coast in the neighborhood of Edinburgh. Roy Soc Edinburgh Trans v 10, p 428-39; also Edinb J Sci v 5, p 98-105.

Stearns, R. E. C.
1886—The *Teredo*, or shipworm. Am Nat v 20, p 131-6, 1 fig.

Stimpson, William.
1863—On the genus *Diplothyra*. Am J Sci & Arts s 2, v 35, p 455.

Sutton, W. D.
1874-8—Burrowing and perforating molluscs. J conchyl v 1, p 49-50.

Teesdale, Clyde H.
1914—Efficiency of various parts of coal-tar creosote against marine borers. Eng Rec v 70, no 41, p 302-3, 2 figs. 7 tabs.

Teesdale, Clyde H., & **Schaekell,** L. F.
1917—Field tests made on oil treatment of wood against marine borers. Eng News Rec v 79, p 833-7. 6 figs. 3 tabs.

Thompson, William.
1834—On the *Teredo navalis* and *Limnoria terebrans* as at present existing in certain localities of the British Islands. Roy Soc Proc v 3, p 291-3 (1834); also Edinb N Phil J v 18, p 121-30 (1835).
1847—Note on the *Teredo navalis* (*T. navalis*, Turton, not Linn.), *Xylophaga dorsalis*, *Limnoria terebrans*, and *Chelura terebrans*, combined in destroying the submerged woodwork at the harbor of Ardrossan on the coast of Ayrshire. Ann Mag Nat Hist v 20, p 157-64.

Tomlin, J. R. le B.
1920—Note on *Xylophaga praestans*, Smith. Malacol Soc London Proc v 14, p 73.

Tryon, George W.
1862—On the classification and synonymy of the recent species of Pholadidae. Acad Nat Sci Philadelphia Proc v 14, p 191-221.
1862—A monograph of the order Pholadacea and other papers. Contr to Conchology no 2. viii, 9-127 p.
1862—Description of a new genus (*Diplothyra*) and species of Pholadidae (*Dactylina Chiloensis*). Acad Nat Sci Philadelphia Proc v 14, p 449-50.
1862—Monograph of the family Teredidae. Acad Nat Sci Philadelphia Proc v 14, p 453-82.
1863—Contributions towards a monography of the order of Pholadacea, with descriptions of new species—no 2. Acad Nat Sci Philadelphia Proc s 2, v 7, p 144-6, pl 1, figs 2-3.
1863—Description of a new species of *Teredo*, from New Bedford, Mass. Acad Nat Sci Philadelphia Proc s 2, v 7, p 280-1, pl 2, figs 3-5.
1865—Descriptions of new species of Pholadidae. Am J Conchology v 1, p 39-40, 285.
1884—Structural and systematic conchology v 3, p 117-28, pls 104-5.

Tur, Jan.
1911—Expériences sur l'action du radium sur le développement de *Pholas candida* Lam. Soc biol Paris Compt rend v 70, p 679-81.

Turton, William.
1819—A conchological dictionary of the British Islands. London. xxii, 272 p, 28 pls.
1822—Conchylia insularum britannicarum. The shells of the British Islands systematically arranged. London. xlvii, 279 p, 20 col pls.

Twelvetrees, N. W.
1922—Reinforced concrete piers and marine borers. Can Eng v 43, p 574-6.

Verkrüzen, T. A.
1871—Bericht über das auffinden der lebenden *Xylophaga dorsalis*, Turton. D Malakozool Ges Nachrbl v 3, p 139-42, 160.
1872—Norwegen, seine fjorde und naturwunder, eine naturwissenschaftiliche reise. Cassel. 188 p 1 pl

Verrill, A. C.
1873—Exploration of Casco Bay by the U S Fish Commission in 1873. Am Assoc Adv Sci Proc 22nd Meeting, pt 2, p 340-95, pls 1-6.

Verrill, A. E., & **Bush,** K. J.
1898—Revision of the deep-water Mollusca of the Atlantic coast of North America, with descriptions of new genera and species. pt I Bivalvia. U S Nat Mus Proc v 20 no 1139, p 775-901, pls lxxi-xcvii.

Vincent, E.
1893—Description d'une nouvelle espèce de Pholadidae (*Aspidopholas staineri*) des environs d'Anvers. Soc malacol Belgique Bull (1891) p lxxxvi-xci, figs.

Vrolik, Girard.
1853—Leendert Bomme, verklaard voor eersten ontdekker van de werktuigelijke wijze, waarop pholaden zich in steen boren. K Akad Wetenschappen, Amsterdam Verslagen en Meded v 1, p 52-63.

Vrolik, Willem.
1853—Sur la question de priorité pour la découverte du mode d'action des pholades dans la perforation des pierres (Extrait d'une lettre de M W Vrolik à M Flourens) Acad sci Paris Compt rend v 36, p 796-7.
1860—Rapport sur le taret. Ann sci nat s 4, v 13 (Zool), p 309-13.

Wilcox, C.
1828—Destructive action of the *Teredo navalis* on vessels built of teak timber. Edinb J Sci v 8, p 151-2.

Williams, Thomas
1851—On the structure of the branchiae and mechanism of breathing in the pholades and other lamellibranchiate Mollusca. Brit Assoc Adv Sci, Rept, 21st meeting Trans Sect p 82; also L'Institute v 19, p 367-8.

Woodward, S. P.
1866—A manual of the Mollusca. 2d ed, London. xiv, 542 p, xxiii pls, map.

Wright, E. Perceval.
1864—On a new genus of Teredinidae. Linnean Soc Trans v 24, p 451-4.
1866—Contributions to a natural history of the Teredidae. Linnean Soc Trans v 25, p 561-8, pls 64-5.

CRUSTACEA

Akademie van wetenschappen, Am-
1893 sterdam. Rapport der Commissie ...betreffende de levenswijze en de werking van *Limnoria Lignorum*. K Akad wetenschappen, Amsterdam, Verhandel 2nd sect, v 1, no 6, 103, xcvi p, vii pls.

Allman, G. J.
1847—On *Chelura terebrans* Philippi: an amphipodous crustacean destructive to submarine timber works. Ann & Mag Nat Hist v 19, p 361-70, pls 13, 14.

Andrews, A.
1875—*Limnoria terebrans* attacking telegraph cable. Quart J Micros Sci n s v 15, p 332.

Barrows, A. L.
1919—The occurrence of a rock-boring isopod along the shore of San Francisco Bay, California. Univ Calif Publ Zool v 19, no 9, p 299-316, pls 15-7.

Bate, C. Spence
1855—On the British Edriophthalma. Brit Assoc Adv Sci Rept 25th meeting p 18-62.
1857—A synopsis of the British edriophthalmous Crustacea. Ann Mag Nat Hist s 2, v 19, p 135-52.
1860—Crustacea. *In* McAndrew, R. List of the British marine invertebrate fauna. Brit Assoc Adv Sci Rept 30th meeting p 217-36.
1862—Catalogue of the specimens of amphipodous Crustacea in the collection of the British Museum. iv, 399 p, lviii pls.
1866—Carcinological gleanings. Ann & Mag Nat Hist s 3, v 17, p 24-31, 2 pls.

Bate, C. Spence and **Westwood,** J. O.
1863-8—A history of the British sessile-eyed Crustacea. London. 2 v, v 1 Amphipoda lvi, 507 p, v 2 Isopoda 536p, figs.

Beddard, F. E.
1886—Preliminary notice of the Isopoda collected during the voyage of H M S Challenger, pt 3. Zool Soc London Proc p 97-122.

Bellonci, G.
1880—Sistema nervoso ed organi dei sensi dello *Sphaeroma serratum*, Atti Accad Lincei s 3 Transunti v 5, p 228-9; Abst in Roy Micros Soc J s 2, v 1, p 886-7 (1881).
1880-1—Ricerche istologiche sull' apparecchio digerente dello *Sphaeroma serratum*, Accad Bologni Rend p 92-93.

Boeck, Axel Jonas.
1872-6—De Skandinaviske og Arktiske amphipoder. Christiania. 711 p, xxxii pls.

Bonnier, Jules.
1896—Édriophthalmes. *In* résultats scientifiques de la Campagne du "Caudan" dans le Golfe de Gascogne, Août September 1895. Fascicule III. Univ Lyons Ann v 26, p 527-689, pls xxviii-xl.

Calman, W. T.
1910—On two new species of wood-boring Crustacea from Christmas Island. Ann & Mag Nat Hist s 8, v 5, p 181-6, pl v.

Chilton, Charles.
1883—Further additions to our knowledge of the New Zealand Crustacea. New Zealand Inst Trans v 15, p 69-86, pls i-iii.
1911—Note on the dispersal of marine Crustacea by means of ships. New Zealand Inst Trans v 43, p 131-3.

1912—Miscellaneous notes on some New Zealand Crustacea. New Zealand Inst Trans v 44, p 128-35.

1914—The species of *Limnoria:* a genus of wood-boring Isopoda. Ann & Mag Nat Hist s 8, v 13, p 380-89, pl xvii.

1914—Distribution of *Limnoria lignorum* (Rathke) and *Limnoria antarctica*, Pfeffer. Ann & Mag Nat Hist s 8, v 13, p 448.

1916—The gribble (*Limnoria lignorum*, Rathke) attacking a submarine cable in New Zealand. Ann & Mag Nat Hist s 8, v 18, p 208.

1919—Destructive boring Crustacea in New Zealand. New Zealand J Sci Tech v 2, no 1, p 3-15, 12 figs.

Clavinad,
1879—La *Limnoria terebrans* auteur des dégâts observés dans les fondations du bâtiment des subsistances. Soc nat sci Cherbourg Mém v 22, p 73-144, pl vii.

Coker, R. E.
1923—Breeding habits of *Limnoria* at Beaufort, N. C. Elisha Mitchell Sci Soc J v 39, nos 1-2, p 95-100.

Coldstream, J.
1834—On the structure and habits of the *Limnoria terebrans*, a minute crustaceous animal destructive to marine wooden erections as piers, etc. Edinb N Phil J v 16, p 316-34, pl vi.

De Kay, James E.
1844—Natural history of the state of New York, Albany pt 6 Crustacea.

Desmarest, Anselme Gaëtan.
1825—Considérations générales sur la classe des crustacés, et description des espèces de ces animaux qui vivent dans la mer, sur les côtes, ou dans les eaux douces de la France. Paris & Strasbourg. xix, 446 p, 56 pl, 5 tab.

Dicquemare,
1783—Ueber ein holzzernagendes seeinsect (*Limnoria terebrans?*). Lichtenberg's Mag Physik v 2, no 2, p 49-53.

Diesen, G. van.
1885-7—Voordracht over de *Limnoria lignorum* en andere crustaceën. K Inst Ingen Tijdschr 1885-6 (verg) p 66-7; 1886-7 (verg) p 20-1.

Edwards, H. Milne.
1834-40—Histoire naturelle des crustacés. Paris. 3 v.

1849—Les crustacés. *In* Cuvier, G. L. Le règne animal. Paris. v 9 and atlas.

Fleming, John.
1842—Crustacea. Encyc Brit. 7th ed v 7, p 592.

Gerstaecker, A. & **Ortmann,** A. E.
1901—Crustacea. *In* Bronn, H. G. Klassen und Ordnungen des Thierreichs. Bd 5, Ab II, 2d H. Isopoda p 8-278, pls ii-xxvi; Amphipoda p 279-543, pls xxvii-xlviii.

Gosse, Philip Henry.
1855-6—A manual of marine zoology for the British Isles. London. 2 v.

Gould, A. A.
1841—Report on the Invertebrata of Massachusetts, comprising the Mollusca, Crustacea, Annelida and Radiata. Cambridge xiii, 373 p, 213 figs on 13 pls.

Hancock, Albany.
1846-50—Notice of the occurrence of *Limnoria terebrans* at the mouth of the Tyne. Tyneside Nat Field Club Trans v 1, p 31-2.

Hansen, H. J.
1905—On the propagation, structure and classification of the family *Sphaeromidae*. Quart J Micros Sci v 49, no 1, p 69-135, pl vii.

Hargar, Oscar.
1879—Notes on New England Isopoda. U S Nat Mus Uroc v 2, p 157-65.

1880—Report on the marine Isopoda of New England and adjacent waters. U S Fish Comm Rept 1878, p 297-462, pl i-xiii; also separate as Doc 32.

Hesse, Eugène.
1868—Observations sur des crustacés rares ou nouveaux des côtes de France. 15th art description d'un nouveau crustacé appartenant au genre *Limnorie*. Ann sci nat s 5, v 10 (Zool), p 101-20, pl 9.

Hewstone, George.
1874—[Note on *Limnoria*.] Calif Acad Sci Proc v 5, p 24.

Hoeck, P. P. C.
1886—*Limnoria lignorum*. Nederland Dierk Ver Tijdschr s 2, v 1, Verslag p cxxvi-cxxx and cxxxviii.

1893—Spiermassa's aan de buikzijde von *Limnoria lignorum*. Nederland Dierk Ver Tijdschr s 2, v 4, p iv.

Holmes, Samuel J.
1904—Remarks on the sexes of *Sphaeromids* with a description of a new species of *Dynamene*. Calif Acad Sci Proc s 3, v 3, p 295-306, pl xxxiv.

1905—The Amphipoda of southern New England. U S Bur Fisheries Bull 24, p 457-541, xiii pls, figs; also separate as Doc 585.

Hope, Frederick Wm.
1835—Observations on the ravages of *Limnoria terebrans*, with suggestions for a preventative against the same. Entomol Soc Trans v 1, p 119-20.

Jones, John Matthew.
1870—Notes on the marine zoology of Nova Scotia. Nova Scotian Inst Sci Proc & Trans v 2, pt 4, p 93-9.

Kirby, W. & **Spence,** W.
1815-26—An introduction to entomology, or elements of the natural history of insects. London. 4 v, figs.

Knower, H. McE.
1896—The development of isopods. Am Naturalist v 30, p 243-8.

Lamarck, Jean P. B. A. de M. de.
1835-45—Histoire naturelle des animaux sans vertèbres. 2d ed. Paris. v 5 1835 Crustacea.

Latreille, P. A.
1829—Les crustacés, les arachnides et les insectes distribués en familles naturelles. *In* Cuvier, G. L. Le règne animal. 2d ed. Paris. v 4.

Leach, William Elford.
1813—Crustaceology. Edinb Encyc. v 7, p 383-437, pl ccxxi.
1813—A tabular view of the external characters of four classes of animals which Linné arranged under Insecta; with the distribution of the genera composing three of these classes into orders, etc., and descriptions of several new genera and species. Linnean Soc Trans v 11, p 306-400 (supp 368-71).

Leidy, Joseph.
1855—Contributions towards a knowledge of the marine invertebrate fauna of the coasts of Rhode Island and New Jersey. Acad Nat Sci Philadelphia J s 2, v 3, p 135-52.

Macdonald, J. D.
1875—On the external anatomy of *Tanais vittatus*, occuring with *Limnoria* and *Chelura terebrans* in excavated pier-wood. Linnean Soc Zool Trans s 2, v I, p 67-70, pl xv.

McMurrich, J. P.
1892—The formation of the germ layers in the isopod Crustacea. Zool Anz v 15, p 271-5, 2 figs.
1895—Embryology of the isopod Crustacea. J Morphology v 11, no 1, p 63-154, 5 pls.

Moll, F.
1915—Holzzerstörende krebse. Naturw Z Forst Landw v 13, p 178-207, 12 figs.

Moore, Edward.
1839—*Limnoria terebrans* in Plymouth Harbour. Mag Nat Hist n s v 3, p 196-7.

Némec, B.
1896—Studie o isopodech. K Bohmisch Ges Wiss Sitzb v 45, p 1-46, 4 pls. Resumé in German, p 36-46.

Pfeffer, G.
1887—Die krebse von Süd-Georgien. pt I. Jahrb wiss Anstalten, Hamburg v 4, p 43-150, pls i-vii.
1889—(Same) pt 2 Die amphipoden. Jahrb wiss Anstalten, Hamburg v 5, p 77-142, pls i-iii.

Philippi, R. A.
1840—*Chelura terebrans*, a new amphipod genus. Ann Nat Hist v 4, p 94-6, pl iii.

Rathke, Heinrich.
1843—Beiträge zur fauna Norwegens (1840). Leop Carol Akad Nova Acta v 20, p 1-264.

Rathke, J.
1799—Jagttagelser henhorende til indvoldeormenes og blöddyrenes naturhistorie; med anmärkningar af O. Fabricius. Kiöbenhavn Nat Selsk Skriv v 5, p 61-153.

Richardson, Harriett.
1897—Description of a new species of *Sphaeroma*. Biol Soc Washington Proc v 11, p 105-7, 3 figs.
1899—Key to the isopods of the Pacific coast of North America, with descriptions of twenty-two new species. Ann Nat Hist s 7, v 4, p 157-87, 260-77, 321-38, 34 figs, also U S Nat Mus Proc v 21, p 815-69, 34 figs.
1901—Key to the isopods of the Atlantic coast of North America with descriptions of new and little known species. U S Nat Mus Proc v 23, p 494-579, 34 figs.
1904—Isopod crustaceans of the Northwest coast of North America. Harriman Alaska expedition, v 10, p 213-230, figs 96-117.
1905—A monograph of the isopods of North America. U S Nat Mus Bull 54, liii, 727 p, 740 figs.
1910—Isopods collected in the Northwest Pacific by the U S Bureau of Fisheries' steamer Albatross in 1906. U S Nat Mus Proc v 37, p 75-129, figs.
1913—Crustacés isopodes. *In* Charcot, J. B. Deuxieme expédition antarctique française (1908-10). Paris. p 1-24, figs.

Rossyskaja-Kojevnikowa, M.
1895—Les organes embryonnaires du *Sphaeroma serratum*, Fabr. Zool Anz v 18, p 151-3, 3 figs.

Samouelle, G.
1819—The entomologist's useful compendium, etc. London. 496 p, 12 pls.

Sars, G. O.
1885—Den Norske Nordhavs expedition, 1876-8, v 14, la & lb 280p, 21 pls, map.
1895-7—An account of the Crustacea of Norway. Christiania & Copenhaven. v 1, 1895 Amphipoda, v 2 1897 Isopoda.

Schaekell, L. F.
1923—Toxicities of coal tar creosote, creosote distillates and individual constituents for the marine wood borer, *Limnoria lignorum*. U S Bur Fisheries Bull 39, p 221-30, figs 1-4.
1923—Studies in protoplasm poisoning. J Gen Physiol v 5, no 6, p 783-805, figs 1-12.

Smith, Sidney Irving.
1880—Occurrence of *Chelura terebrans*, a crustacean destructive to the timber of submarine structures, on the coast of the United States. Smithsonian Misc Coll 19, art 2, p 232-5. 2 figs.

Stebbing, T. R. R.
1900—On some crustaceans from the Falkland Islands collected by Mr. Rupert Vallentin. Zool Soc London Proc p 517-68, pls xxxvi-xxxix.
1904—Gregarious Crustacea from Ceylon. Spolia Zeylanica v 2, p 1-29, 1 fig, pls 1-6.
1906—Marine crustaceans, XII. Isopoda, with description of a new genus. *In* Gardiner, J. Stanley, *ed.* The fauna and geography of the Maldive and Laccadive archipelagoes. Cambridge. v 2, pt iii, p 699-721, pls xlix-liii.
1908—South African Crustacea, pt 4. South African Mus Ann v 6, p 1-96, pls 27-40.

Stevenson, David.
1862—Notice of the ravages of the *Limnoria terebrans* on creosoted timber. Roy Soc Edinb Proc v 4, p 612-6.
1875—Notice of the ravages of the *Limnoria terebrans* in greenheart timber. Roy Soc Edinb Proc v 8, p 182-5.

Stevenson, Robert.
1825—Account of the erection of the Bell Rock lighthouse. Edinb Phil J v 12, p 18-38, pl I.

Tattersall, W. M.
1913—The Schizopoda, Stomatopoda and non-Antarctic Isopoda of the Scottish National Antarctic Expedition. Roy Soc Edinb Trans v 49, p 865-94, 1 pl.

Teesdale, Clyde H.
1914—Marine wood borers: little known crustaceans of destructive habits. Sci Am S v 78, p 356-7, 9 figs.

Templeton, Robert.
1836—Catalogue of Irish Crustacea, Myriopoda and Arachnoida; selected from the papers of the late John Templeton, with additions. Mag Nat Hist v 9, p 9-14.

Thompson, G. M.
1881—Recent additions to the notes on New Zealand Crustacea. New Zealand Inst Trans v 13, p 204-21, pls vii-viii.

Troschel.
1912—Holzzerstörer unter Wasser. Centrallblatt Bauverw v 32, p 394-5, 5 figs.

Valle, Antonio della.
1893—Gammarini del Golfo di Napoli. *In* Naples Zool Station, Fauna und flora des Golfes von Neapel, no 20, xi, 948 p.

Verrill, A. C.
1873-4—Results of recent dredging expeditions on the coast of New England, Am J Sci & Arts s 3, v 5, p 1-16; v 6, p 435-41; v 7, p 38-46, 131-8, 405-14, 498-505, pls iv-v.

White, Adam.
1847—List of the specimens of Crustacea in the collection of the British Museum. London. viii, 143 p.
1857—A popular history of British Crustacea. London. xii, 358 p, xx col pls.

WOOD PRESERVATION

Achatz, R. V.
1920—Preservative treatment of wood poles. Purdue U Pub Eng Dept v 4, no 2.

Addison, G. H.
1911—Destruction of a timber jetty by the sea worm, and its reconstruction in Billian. Royal Eng J v 14, Aug. p 103-8.

Adsett, F. C.
1920—Utilizing electric current for treating of wood poles. Canadian Eng v 39, p 215.

Alexander, Charles Armstead, jr.
1864—Preservation of wood. Smithsonian Inst Ann rept, 1864. Washington 1865, p 196-205. Translated from the Leipzig Aus der Natur, usw.

Alleman, Gellert.
1907—Methods and economic aspects of modern timber preservation. Eng Club Phil Pro p 219-53.
1907—Quantity and character of creosote in well-preserved timber. Forest Service Cir no 98, 16 pp.
1914—Quantity and character of creosote in well preserved timbers. Am Wood Preservers Assoc Pro v 10, p 88-96, Chem Abstr v 9, p 855.

Allerton, David.
1908—Treating wood that is refractory to treatment and also subject to decay. Eng News v 59, p 182.
1911—Depths of penetration in wood preservation. Ry & Eng Rev v 51, p 44-5.

American Railway Engineering and Maintenance of Way Association.
1907 Experience with treated ties, abstract of report of committee on ties. Eng News v 57, p 359-60.
1909—Report of Committee no 17, on wood preservation. Ry & Eng Rev v 49, p 258-9.
1914-23—Report of Committee no 17, on wood preservation. Am Ry Eng Assoc Pro v 15, pt 1, p 625-81; v 16, pt 1, p 825-90, v 17, pt 1, p 447-82, v 18, p 1261-89, v 20, p 119-33, v 21, p 321-64, v 22, p 443-72, v 23, p 899-997, v 24, p 943-1041.
1924—Report of Sub-Committee on marine piling research. Bul 265, p 901-1066.

American Society of Civil Engineers.
1885 Preservation of timber; report of the committee on the preservation of timber presented and accepted at the annual convention, June 25, with appendices on the preservation of timber and the preservation of forests. Am Soc Civil Eng Trans v 14, p 247-387.

American Wood Preservers' Association.
1919 Surface tensions of wood preserving oils as factors in protection against marine borers. Am Wood Preservers Assoc Pro v 15, p 113-23, Eng. & Contr v 53, p 91.

American Wood Preserving Company.
1875 Thilmany process; sulphate of baryta, especially adapted for railroad ties, telegraph poles, wood pavement blocks, etc., Cleveland.

Anderson, J.
1873—Bericht über die bis jetzt gelegten unterseeischen kabel. Dinglers polytech J v 207, p 119-25; Telegraphic J v 1, p 5-9.

Andés, Louis Edgar.
1895—Das conservieren des holzes. Vienna, Hartleben.

Andrews, Edward R.
1878—Hayford process and apparatus for preserving timber. J Frank Inst v 105, p 109-18, 180-6.
1878-9—Wood preserving by creosote, Hayford process. Inst Civil Eng Pro v 56, p 300; abstr from Eng Club Phila v 1, p 80-3.

Angier, F. J.
1903—Operation of the Burlington tie treating plant. Ry Age v 36, p 283-7.

1910—Economy of treated crossties. Eng Rec v 61, p 246-7.

1910—Proper grouping of timbers for treating. Southern Lumberman, v 62, no 748, p 31-2.

1911—Costs of treating seasoned and unseasoned ties. Eng Rec v 65, p 76-7, Eng News v 67, p 241, Chem Abstr v 6, p 2160.

1911—Keeping records of treated ties. Eng News v 65, p 143.

1912—Treating seasoned vs unseasoned ties. Am Wood Preservers Assoc Pro v 8, p 220-3, Ry & Eng Rev v 52, p 63.

1915—Leaching of zinc salts and effects of improper drainage. Am Wood Preservers Assoc Pro v 11, p 75-80, Chem Abstr v 9, p 2138.

1915—Tie preservation in the Baltimore and Ohio Railroad. Ry Rev v 57, p 630-3.

1915—Wood preservation. Wood preserving v 2, no 4, p 72-3.

1915—Wood preservation; its past, present and future. Lumber Wld Rev v 29, no 9, p 42-6, Nov 10.

n. d.—Notes on seasoning and treatment of lodgepole pine ties. Manuscript rept, 8-P-12-5.

Angier, F. J. and others.
1914—Various phases in the details of timber preservation, abstracts of five papers, presented at recent convention of Wood Preservers at New Orleans. Eng Rec v 69, p 99-100.

Annand, J. F.
1914—Preservative treatment of timber for estate purposes. Quart J For v 8, p 169-86.

Antiseptische behandlung des holzes.
1901 Dinglers polytech J v 316, p 548.

Anwendung des imprägnierverfahrens
1902 Hasselmann auf schwellen und nutzholz. Glückauf v 38, p 104-6.

Apparatus for creosoting railroad ties.
1885 Sci Am Sup v 20, p 8234-5.

Armstrong, A. K.
1913—Woods used for piling. Forest products Laboratory manuscript rept, pt 1-2.

1916—Greenheart, A timber with exceptional qualities. Eng Rec v 73, p 149-50, 180-1.

1917—Protecting the bottoms of wooden ships. Am Lumberman no 2220, p 52-3. Dec 1.

Arn, W. G.
1909—Durability of creosoted piles in Caribbean Sea and Gulf coast between Mobile and New Orleans. Eng News v 61, p 73.

Ashmead, D. C.
1920—Three or twelve years for mine timbers? Coal Age v 18, p 281-2.

Ayer and **Lord** Tie Company's Carbon-
1903 dale preserving plant. Ry Gaz v 35, p 664-5.

Bailey, Irving W.
1913—Preservative treatment of wood. Forest Quart v 11, p 5-20.

Baist.
1862—Nouvelles expériences sur la conservation des bois, au moyen du sulfate de cuivre et du goudron. Soc de l'Encouragement Bul v 61, p 441-2; from Dinglers polytech J.

Baker, H. P.
1907—Treatment of fence posts to increase durability. Forestry Q v 5, p 399-402.

Balden, J.
1907—Creosoting of timber by absorption. Roy Scottish Arboricultural Soc Trans v 20, p 62.

Barger, G.
1922—Report on the investigation of the protection of timber against teredo attack. Second (Interim) rept Com Inst C E on deterioration of structures in sea water, p 33-4.

Barker, J. M.
1916—Strength of burnettized timber. Eng News v 75, p 1084-5, Chem Abstr v 10, p 2290.

Barker, R.
1910—Protection of piles in sea water. Eng Mag v 39, p 414-16.

Barnes, T. Harvard.
1911—Notes on pile protection. Assoc Eng Soc J v 47, p 101-5.

Barnum, C. T.
1910—Wood preservation from an engineering standpoint. W Soc Eng J v 15, p 346-66, Chem Abstr v 5, p 381.

Barre, H. W.
1919—Creosoting fence posts. South Carolina Agr Exp Sta Bul 201, 15 p. Chem Abstr v 14, p 108.

Barshall Impregnating Co. Treatise on
1900 wood preservation with special reference to a new German process (Hasselmann patents) that is thorough, reliable and permanent. (New York) p 32.

Barth, K. C.
1917—Economic importance of wood preservation. Eng & Min J v 104, p 985-8, Chem Abstr v 12, p 302.

1917—Preservation of poles from decay. Telephony v 72, no 13, p 16-19, Chem Abstr v 11, p 1895.

1917—Wood preservation; its importance to the lumber industry. Lumber World Rev v 32, no 11, p 27-8, June 10.

1917—Wood preservation; methods of treatment. Lumber World Rev v 33, no 4, p 19-21, Aug 25.

1917—Wood preservation; the most practical manner in which this may be done. Lumber World Rev v 33, no 1, p 23-4. July 10.

1918—Modern development and practical details in the preservative treatment of wood. Am Soc Agr Eng Trans v 12, p 75-87.

1918—Preservative treatment of mine timbers as a conservation measure. Coal Age v 14, p 1025-7.

1918—Wood preservation; a valuable aid in promoting lumber sales. Lumber World Rev v 34, no 8, p 29-31, Apr 25.

Bass, F. H.
1906—Preservation of timber. Eng Soc Minnesota U Year Book v 14, p 31-8

Bateman, E.
1911—Modification of the sulfonation test for creosote. Forest Service Cir no 191, Chem Abstr v 6, p 1063.
1911—Visual method for determining the penetration of inorganic salts in treated wood. U S Forest Service Cir no 190, Chem Abstr v 6, p 1063, Eng News v 66, p 705, Eng & Min J v 92, p 1218, Chem Abstr v 6, p 539-40.
1912—Quantity and quality of creosote found in two treated piles after long service. Forest Service Cir no 199, Chem Abstr v 7, p 1275.
1914—Method for determining the amount of zinc chloride in treated wood. J Ind & Eng Chem v 6, p 16-18, Chem Abstr v 8, p 1003.
1915—Report of committeee on wood preservatives. Am Woodpreservers Assoc Pro v 11, p 131-40, Chem Abstr v 9, p 2301.
1916—Relation between the specific gravity of zinc chloride solutions and their concentrations. Wood Preserving v 3, p 54-6, Chem Abstr v 10 p 2513.
1920—Inaccuracy of treating methods due to moisture in wood. Chem & Met Eng v 22, p 57-9, Chem Abstr v 14, p 1025.
1920—Leaching of zinc chloride from treated wood. Am Ry Eng Assoc Bul v 22, no 227, p 73-87, Chem Abstr v 14, p 3304.
1920—Relation between viscosity and penetrance of creosote into wood. Chem & Met Eng v 22, p 359-60, Chem Abstr v 14, p 1206.
1920—Theory of the mechanism of the protection of wood. Ry Signal Eng v 13, p 259, Am Wood Preservers Assoc Pro v 17, p 506-14, Chem Abstr v 14, p 1023.
1920—What light creosote oils have done in wood preservation. Am Wood Preservers Assoc Pro v 16, p 44-55, Chem Abstr v 14, p 1024.
1922—Coal tar and water gas tar creosotes; their properties and methods of testing. U S Dept Agr Bul no 1036.
1922—Theory on the mechanism of protection of wood by preservatives. Am Wood Preservers Asso Pro v 18, p 70-89.

Bateman, Ernest and **Town,** G. G.
1920—Report on laboratory experiments to determine the loss of creosote by evaporation from open-tank treatments. Am Wood Preservers Assoc Pro v 16, p 83-91.

Baterden, J. R.
1903-4—Creosoting timber. Inst Civil Eng Pro v 158, p 141-2.

Baumhauer, E. H. von.
1866—Sur le taret et les moyens de préserver le bois de ses dégâts. Archives néerlandaises des Sciences Exactes et Naturelles, I p 1-45.

Bedford, M. H. and **Pfanstiel,** R.
1914—New method for the determination of zinc in treated wood. J Ind & Chem v 6, p 811, Chem Abstr v 9, p 139.

Belcher, R. S.
1913—Effect of initial air pressure on penetration of creosote. Eng Rec v 67, p 299-300, Chem Abstr v 7, p 1795.

Benham, Claude Gilbert.
1917—Open-tank treatment of timber urged for small railroads. Eng News v 79, p 152.

Berlin Mills Co. Selection of structural
1913 wood and its preservation from decay. Portland, Me. 25 p.

Berry, James B.
1917—Prolonging life of farm timbers. Georgia State Col Agr ext Division Cir 66.

Besson, M. H.
1901—Conservation des Bois par le Procédé Rutgers. Mem Soc Ing Civil de France v 1, p 689-713.

Bethell, J.
1842—Preservation of timber. Inst Civil Eng Pro v 2, p 68, 88-9.
1849-50—Mode of creosoting and one result of its application at Lowestoft Harbor. Inst Civil Eng Pro v 9, p 50-3.
1851-2—Assumed inflammability of creosoted timber. Inst Civil Eng Pro v 11, p 296.
1852-3—Kyan, Margary and Paynes processes for preserving timber. Inst Civil Eng Pro v 12, p 223-30.
1858-9—Comparative value of creosoted and kyanized timber for marine works. Inst Civil Eng Pro v 18, p 429-32.
1859-60—As to creosoting timber. Inst Civil Eng Pro v 19, p 666-7.
1860—On building woods. The cause of their decay and the means of preventing it. Civil Eng & Arch J v 23, p 190-6.

Betts, H. S. and **Newlin,** J. A.
1915—Strength tests of structural timbers treated by commercial wood preserving processes. U S Dept Agr Bul 286, Chem Abstr v 10, p 108.

Bixby, William H.
1880—Creosoting timber. Railroad Gazette v 12, p 267-8.
1887—Report on wood-creosote oil. U S Bur of Forestry Bul 1, p 99-103.
1901—Creosoted ties on English Railways. Ry & Eng Rev v 41, p 830-1.
1906—Creosoted wood pavement. Am Lumberman July 21. p 26.
1907—Creosoting of home-grown timber. Quart J Forestry v 1, p 49-52.
1908—Creosoted wood block pavement well established in America. Am Lumberman Aug 15, p 34.
1909—Creosoted wood as a paving material. Am Lumberman no 1756, p 33. Jan 16.
1909—Creosoted wood block pavements. Eng News v 61, p 176-7.

Blake, E. M.
1920—Application of the perforating process in the preservative treatment of wood with especial reference to Douglas fir. Boston Soc Civil Eng J v 7, p 99-126.

1920—Data on preservative treatments prove that increased service fully justifies cost. Am Lumberman no 2346, p 62-3, May 1.

1920—Methods of wood preservation. Timberman v 21, no 7, p 87-9.

1920—Perforating process for timber treatment. Am Wood Preservers Assoc Pro v 16, p 55-73, Eng & Contr v 53, p 457; Chem Abstr v 14, p 1747.

Boas, I. H.
1920—Preservation of piling against marine borers. Australian For J v 3, no 10, p 315-6, Oct.

Bond, F. M.
1912—Use of treated wood paving blocks. Eng Rec v 65, p 223-4, Chem Abstr v 6, p 1063.

1913—Experiments in the preservative treatment of red oak and hard maple cross-ties. U S Forest Service Bul no 126, Eng Rec v 67, p 728-9, Chem Abstr v 7, p 2849.

1913—Some tests to determine the effect upon absorption and penetration of mixing tar with creosote. Am Wood Preservers Assoc Pro v 9, p 216-87.

Bond, Paul.
1917—Durability of timber in Cleveland break-water. Prof Mem Eng Corps U S Army v 9, p 355-7.

Boucherie.
1840—Precédés de conservation de bois. Soc de l'Encouragement Bul v 39, p 151-2.

1841—Conservation de bois. Soc de l'Encouragement Bul v 40, p 192-30.

1845—Conservation des traverses de bois des chemins de fer. Soc de l'Encouragement Bul v 44, p 549-52.

Boulton, Samuel Bagster.
1883-4—On the antiseptic treatment of timber. Inst Civil Eng Pro v 78, p 97-211, Van Nostrand's Eng Mag July & Aug, p 29-47, 114-33, 204 15.

1885—The preservation of timber by the use of antiseptics. Van Nostrand, N. Y.

Bowers, M. A.
1914—Creosoted piles on Pacific coast. Eng Rec v 70, p 66-7.

Bowser, E. H.
1905—Preservation of timber with antiseptics. Min Wld v 23, p 13-4, Wood Craft v 4, no 1, p 26-30; Assoc Eng Soc J v 34, p 159-70.

Bradley, Harlow.
1916—Service tests of treated and untreated fence posts. Am Ry Eng Assoc v 18, no 187, p 39-53, Chem Abstr v 10, p 254-6.

Bréant.
1845—Appareil pour pénétrer le bois de substances propres à le préserver. Soc de l'Encouragement Bul v 44, p 254-6.

Brewer, Wm. H.
1893—Preservation of wood from decay. Conn Board Agr rept, p 50-61.

Bright, E. W.
1914—Economical use of wood and preservation of timber. Elec Ry J v 44, p 1351-2.

Britton, T. A.
1875—Treatise on the origin, progress, prevention and cure of dry rot in timber, with remarks on the means of preserving wood from destruction by sea worms, etc. Spon, London. 311 p.

Brunet, Raymond.
1902—Conservation des bois par l'électricité. Rev des Eaux et Forêts v 41, p 688-89.

Buchanan.
1877—On the means of selecting the most durable timber. New Zealand Inst Trans & Pro v 10, p 190.

Buehler, W.
1911—Creosote and zinc chloride as a wood preservative. Eng & Min J v 92, p 57, Chem Abstr v 5, p 2937.

1911—Timber preservation; its development and present scope. Am Soc Civil Eng Trans v 11, p 364-73, discussion p 374-400.

1916—Creosoted wood-block paving. Wood preserving v 3, p 57-8, Chem Abstr v 10, p 2513.

Burlington Tie preserving plant at 1908 Galesburg. Ry Age v 45, p 667-70.

Burnell, C. R.
1859-60—Creosoted timber and the capability of greenheart timber to resist the attacks of the teredo. Inst Civil Eng Pro v 19, p 665-6.

Burt, H. P.
1853—On the nature and properties of timber with descriptive particulars of methods now in use for its preservation from decay. Inst Civil Eng Pro v 12, p 206-43, Civil Eng & Arch J v 16, p 75-6.

Busbridge, Harold.
1904—Shrinkage and warping of timber. Sci Am S v 58, p 24032-3.

Bush, L.
1907—Treatment of railroad ties and the materials available for this purpose in New Jersey, New York and Pennsylvania. Eng Rec v 55, p 482-5.

Cabot, S.
1912—Phenomenon of the apparent disappearance of the higher boiling phenols in creosoted wood and its explanation. J Ind & Eng Chem v 4, p 266-7, Chem Abstr v 6, p 1513.

Campbell, A. B.
1917—Butt treatment of wooden poles. Iowa State Col Agr & Mech Arts Eng Ext Dept. Tech Service Bul no 28.

Card, J. B.
1908—Open tank method of preserving timber; results obtained with ties and paving blocks. Eng News v 60, p 528, Chem Abstr v 3, p 373.

1915—Steaming ties. Am Wood Preservers Assoc Pro v 11, p 103-10, Chem Abstr v 9, p 2139.

1917—Report of committee on terminology. Am Wood Preservers Assoc Pro v 13, p 76-81, Chem Abstr v 11, p 396.

Carlin, J. P.
1915—Experience with protected timber poles in tropical waters at San Juan P. R. Cornell Civil Eng v 24, p 50-4.

Castle, L.
1914—Preservation of wood. Roy Soc Arts J v 62, p 342-3, Chem Abstr v 8, p 1656.

Caws, Frank.
1899—Haskinized wood. Roy Inst Brit Arch J ser 3, v 6, p 270-4.

Chanute, Octave.
1891—Result of tests on wooden discs subjected to various treatments. Eng Rec v 24, p 400, from Comptes Rendus.
1894—Results of timber preservation by Wellhouse process. Eng News v 31, p 547.
1895—Preservation of wood. Cassier's Mag v 7, p 301-7.
1900—Preservation of railway ties in Europe. Am Soc Civil Eng Pro v 26, p 900-27, v 27, p 11-2, Am Soc Civil Eng Trans v 45, p 498-549, Ry & Eng Rev v 40, p 243-4.
1900—Preservation treatment of timber. Information concerning the processes tried and the results attained. The work as carried on in Europe and the processes in vogue. W Soc Eng J v 5, p 100-26.
1900—Tie treating. Ry Gaz v 32, p 211.
1907—Steaming of timber. Munic Eng v 33, p 237-40.
1913—Steaming timber before treating with preservatives. Ry & Eng Rev v 47, p 173-4.

Chanute, Octave, and **Allerton,** David.
1907—Steaming of timber before treating with preservative. Eng News v 57, p 138-40.

Chapman, C. M.
1915—Fungus bed test of wood preservatives. Am Soc Test Mat Pro v 15, pt 2, p 267-73.

Cherrington, F. W.
1910—Preservation of wood. Min Wld v 33, p 1182, Chem Abstr v 5, p 991.
1911—Asphaltic oils for the preservation of railway ties. Eng News v 65, p 122-3, Chem Abstr v 5, p 1334.
1911—Asphalt oils as economical wood preservers. Munic Eng v 40, p 411-3, Chem Abstr v 5, p 1334, 3150.
1913—Wood preservation with asphalt material. Munic Eng v 44, p 192-3, Chem Abstr v 7, p 1795.
1916—Creosoted piling and poles. Am Wood Preservers Assoc Pro v 12, p 61-70.

Cheyney, E. G.
1913—Preservative treatment of fence posts. Minnesota U Dept Agr Ext Division Ext Bul no 40, Minnesota Farmers' Library v 4, no 4.

Christian, E. S.
1915—Destruction of timber by marine borers. Am Wood Preservers Assoc Pro v 11, p 296-304, Ry Age Gaz v 58, p 162-3.

Church, S. R.
1911—Some recent publications on creosote oil. Soc Chem Ind J v 39, p 191-3, Chem Abstr v 5, p 2328.

Clark, W. D.
1915—An economical method of wood preservation. Timberman v 16, no 6, p 30-2 Apr.

Clarke, Alfred H.
1915—Zinc chloride as a preservative. Wood preserving v 2, p 74, Chem Abstr v 10, p 1088.

Clarke, F. W.
1873—An essay upon the preservation of wood from decay; with particular reference to the protection of wood paving. (Boston, Mass.) Wooden Pavements, Commission appointed to investigate the Matter of. rept. 27 p. City Document no 100. Boston.

Clegg, S.
1852—Action of the seaworm on timber. J Frank Inst v 53, p 38-40, from London Architect.
1867—Attacks of the teredo on timber ships. J Frank Inst v 84, p 20.

Coates and others.
1900—Preservation of timber. W Soc Eng J v 5, p 248-54.

Cobley, Thomas.
1862—Procédé pour durcir le bois et le rendre incombustible. Soc de l'Encouragement Bul v 61, p 179, from Newton's London Journal.

Coderre, J. A.
1921—Application of wood preservation to Canadian timber products. Canadian Lumberman v 41, no 6, p 92-3, Mar 15.

Collins, S. H. and **Hall,** A. A.
1914—Use of coal tar creosote and naphthalene for preserving wooden fences. Soc Chem Ind J v 33, p 466-8, Chem Abstr v 8, p 3108.

Collstrop, A. and **Bülow,** Edv.
1919—Impraegnering af hafnetommer Ingenioren v 28, p 69-74.

Colthurst, J.
1842—Amount of saturation of timber in process of kyanizing. Inst Civil Eng Pro v 2, p 84.

Complete wood preserving plant mounted on cars. Ry Age v 67, p 453-5, Sci Am Sup v 88, p 332-3, Eng & Contr v 52, p 334.
1919

Compulsory use of fire-proofed wood in New York City building construction. Eng News v 52, p 71.
1904

Conclusive record for creosoted piles. Ry Maintenance Eng v 16, p 23-5, Ry Age v 68, p 247-9.
1920

Condition of creosoted piles after 25 years. Eng News v 62, p 176.
1909

Conservation de bois, procédés employés en Angleterre. Soc de l'Encouragement Bul v 38, p 139-40.
1839

Conservation de bois. Soc de l'Encouragement Bul v 39, p 497.
1840

Conservation de bois, procédé Boucherie. Soc de l'Encouragement Bul v 41, p 511.
1842

Conservation de bois, procédé Bréant. Soc de l'Encouragement Bul v 43, p 189-90, 316, 388-9, v 44, p 254-6.
1844-5

Conservation des bois par la naphtaline. 1853—Soc de l'Encouragement Bul v 52, p 81.

Conservation des traverses de chemins 1907 de fer. Génie Civil v 50, p 444.

Conservation des poteaux en bois par 1920 injection de fluorure de zinc. Génie Civil v 58, p 465, from Electrotech und Maschinenbau.

Conservation de bois. Procédé Bedell. 1853 Soc de l'Encouragement Bul v 52, p 82-3.

Cooper, John.
1840—Action of the worm on kyanized timber. Inst Civil Eng Pro v 1, p 91-2.

Cowper-Coles, Sherard.
1899—Some notes on fireproofing and preserving timber. Industries & Iron v 27, p 267-8; Engineering v 67, p 258-9.

Craig, A. D.
1902-3—Damage done by the teredo at Riley's Hill dry dock, Richmond River, N. S. W. Inst Civil Eng Pro v 152, p 193-4.

Cram, Thomas Jefferson.
1871—Report upon the decay and preservation of timber. Made in response to request from the office of the Chief of Engrs, U S A of 9th of September, 1870, for a report upon the creosoting of timber. Washington, D. C. (Eng Dept) 38 pp.

Crawford, Carl G.
1904—Open tank treatment of timber. U S Bureau of Forestry Cir 101.
1907—Brush and tank pole treatments. Forest Service Cir 104.
1907—Line of advance in wood preservation. Eng News v 57, p 155-6.

Creo-resinate wood preserving plant. 1900 Eng Rec v 42, p 278-80.

Creosote as a timber preservative. Eng 1911 & Min J v 90, p 1295, Chem Abstr v 5, p 784.

Creosote for the preservation of timber. 1921 Coll Guard v 122, p 1001.

Creosoted piles. Condition after 15 1909 years, bridge from Galveston, island to mainland. Eng News v 61, p 23-4.

Creosoted piling resists marine borers. 1919 Timberman v 20, no 10, p 36-7.

Creosoting timber. Ry Gaz v 22, p 895, 1890 898-9.

Creosoting loblolly cross arms. U S 1911 Forest Service Cir 151, Chem Abstr v 5, p 380.

Creosoting plant of the Pacific creosot-1911 ing Company, Eagle Harbor, Washington. Eng News v 64, p 473, Chem Abstr v 5, p 380.

Creosoting process of Seely; preserva-1870 tion of timber from decay and attacks of marine worms. European rept American Repts, 76 p.

Creosoting works of Ricker and Lee at 1894 Galveston, Texas. Eng News v 31, p 296-7.

Creosoting works of the Western Rail-1905 way of France. Eng News v 54, p 87-8.

Cross-ties purchased and treated in 1915. 1915 U S Dept Agr Bul no 549.

Curtis, J. G. C.
1847—Timber ravages of the teredo and terebrans. Inst Civil Eng Pro v 6, p 54-5.

Curtis, W. G.
1895—Method of creosoting used at the Oakland Works. Ry Gaz v 27, p 80, 89, Sci Am S v 39, p 16073-5; Eng News v 38, p 218-19.
1895—Timber preserving methods and appliances; the portable wood preserving plant of the Southern Pacific Railway for creosoting, Burnettizing and other treatment. Assoc Eng Soc J v 15, p 1-25.

Curtis, Walter W.
1899—Artificial preservation of railroad ties by the use of zinc chloride. Am Soc Civil Eng Pro v 25, p 201-53, discussion p 460-78, 551-3, 698-706, 1050-6.
1903—Timber treating plants. W Soc Eng J v 8, p 541-60.
1904—Timber treatment and timber treating plants. N Y Ry Club Pro v 14, p 202-16, discussion p 216-24, Ry & Eng Rev v 44, p 375-7, 409-10.
1907—Some notes on tie preservation. Am Ry Maintenance of Way Assoc Pro v 8, p 491-5, Ry Age v 43, p 471-2.

Dagneau.
1835—Goudron vermifuge propres à la conservation des bâtiments de mer. Soc de l'Encouragement Bul v 34, p 542-3.

Dane.
1921—Om beskyttelsesmidler mod angreb af paeleorm og paelekrebs. Ingenioren v 30, p 425.

Davison, R.
1842—Remarks on the ravages of the worm, teredo navalis, in timber. Inst Civil Eng Pro v 2, p 90-1.

Dean, Arthur L.
1908—Estimation of moisture in creosoted wood. Forest Service Circ 134.

Dean, Arthur L. and **Downs**, C. R.
1912—Antiseptic tests of wood preserving oils. 8th Inter Congr Appl Chem v 13, p 103-10, Chem Abstr v 8, p 3178, 1096, v 7, p 3020.

Deavux and **Bouygues.**
1920—Efficiency of sodium fluoride as an antiseptic for treatment of railroad ties. Comptes Rendus v 170, p 1006-8, Chem Abstr v 14, p 2066.

Decombes.
1861—Sur le port de Capbreton. Ann des Ponts et Chaussées series 4, v 2, pt 2, p 129-51.

De Lafollye.
1881—Sur la conservation des bois par le sulfate de cuivre. Soc de l'Encouragement Bul v 80, p 422-5.

Determining penetration of wood pre-1922 servatives. Forest Products Laboratory Tech notes no 163.

Diaz, Carlos.
1916—Durability of wood paving in the city of Tucuman. Chem Abstr v 12, p 1695, from Tucuman U Dept Investigations.

Does chemical treatment of ties increase
1901 the hardness of wood and the holding power of the spike? Ry & Eng Rev v 41, p 672.

Downing, M. A.
1899—Wood pavements. Eng Rec v 40, p 455.
1900—Creosoted wood block pavements in Indianapolis. St Ry Rev v 10, p 92.

Draper, J. E. G.
1916—Wood preserving plant at Newark, N. J. Wood preserving v 3, p 76, Chem Abstr v 11, p 199.

Dry rot in timber.
1907—Builder v 93, p 543-4.

Dry rot in timber, its cause and preven-
1908 tion. Sci Am S v 65, p 43-3.

Dudley, P. H.
1886—Fungi inducing decay in timber. Sci Am S v 21, p 8596-7.
1886—Woods and their destructive fungi. Pop Sci Mo v 29, p 433-44, 604-17.
1919—Fungi, the cause of decomposition of timber. Am Ry Eng Assoc Bul v 21, no 217, p 49-63.

Dumesny, P.
1901—Séchage rapide et ignifugation du bois. Rev Chémie Industrielle, v 12, p 211-6, 241-5. Sci Am S v 54, p 22306-7.

Dundon, P. F.
1906—Experience in creosoting Douglas fir. Eng News v 55, p 159.

Dunn, O. T.
1905—Methods and cost of creosoting timber. Eng News v 53, p 443-4.

Dunn, S. Wrenne, **M. J. C.** and **Jones,** A. G.
1897—Chemical preservation of crossties. Ry Rev v 37, p 551-2.

Durability of treated and untreated pil-
1921 ing above mean low water. Mimeographed article. Forest Products Laboratory in cooperation with Wisconsin U (Madison, Wis.)

Dutting, C.
1898—The suitability of certain woods for mine timbering. Coll Guard v 76, p 781-2.

Dutton, Ellis R.
1915—Some experiences in creosoted wood-block paving. Am Soc Munic Improvements Pro 1915, p 167-77, Chem Abstr v 10, p 1420.

Effect of preservative agents on mine
1891 timber. Eng & Min J v 51, p 633.

Effect of salt impregnation on timber.
1912—Eng Rec v 65, p 134, Chem Abstr v 6, p 924.

Electrical process for preserving wood.
1902—Sci Am v 86, p 191; from Praktischer Maschinenkonstructeur.

Electricity and the seasoning of timber.
1898—Architect (London) v 60 Dec. 9, p 19-20.

Ellis, G. H.
1889—Report of experiments in wood seasoning. Forest Service Bul no 3, p 57-62.

Elsner, Jules.
1904—Fungi in mining timber. Iron & Coal Tr Rev v 68, p 678.

Embree, C. J.
1922—Greenheart as teredo resistant on Panama locks. Eng News v 89, p 619-21.

Entomology and Architecture.
1921—Am Inst Arch J v 9, p 182-3.

Eppinger and **Russell.**
1908—Expert observation concerning coal tar creosote for preserving timber. Am Lumberman no 1708, p 32-3, Feb 15.

Ericson, J.
1912—Wood block pavements in Chicago. Eng Rec v 65, p 10; Chem Abstr v 6, p 798.

Escard, J.
1914—Procédés d'imprégnation des bois et notamment des poteaux des lignes de transport d'énergie électrique. Lumière Elec v 26, p 806-16.

Falck, R
1919—Laboratory tests on the value of preservatives for timber and plants and a new solution for spraying plants. Chem Zeit v 43, Rep 313; Chem Abstr v 14, p 1423.

Falkenburg, M. J.
1914—Creosoting Douglas fir. W Engineering v 4, p 438-42.

Faucette, W. D.
1911—Marine wood destroyers in the waters of the South Atlantic ports. Eng News v 65, p 12-3; Chem Abstr v 5, p 1334.

Faulkner, E. O.
1907—Crude oil for preserving ties. Ry Age v 43, p 180.

Fernow, B. E.
1890—Consumption of forest supplies by railroads and practicable economy in their use. Forest Service Bul no 4.
1890—Preserving Processes. Forest Service Bul no 4, p 359.
1898—Increasing the durability of timber. (Washington) 5, p Forest Service Circ. no 20.

Ferrell, Jos. L.
1901—Discussion of recent developments in fire-proofing of wood, p 17. J Frank Inst v 151, p 161-77.
1903—Apparatus for and methods of treating wood to protect it from fire and preserve it from decay. Eng Club Phil Pro v 20, p 209 30.
1903—Concerning tie preservation. Ry & Eng Rev v 43, p 441.
1903—Protection and preservation of wood. Am Arch v 81, p 12-3.
1904—Preservation of wood from fire and decay. W Soc Eng J v 9, p 38-43.

Fifth Annual Convention of the Wood
1909 Preservers' Association. Eng News v 61, p 114-5; Chem Abstr v 3, p 1685.

Flad, Henry.
1887—Wood preservation. Forest Service Bul no 1, p 66-98.

Fleming, R. M., and **Humphrey,** C. J.
1915—Toxicity of various wood preservatives. J Ind & Eng Chem v 7, p 652-8, Chem Abstr v 9, p 2580.

Folsom, H. P.
1907—Sterilization and preservation of poles. Am Telephone J v 15, p 271-2.
1907—Sterilization and preservation of electric line poles. For & Irrig v 13, p 651-5.
1909—Preservation of telegraph poles. Railroad Age Gaz v 47, p 111-12; Chem Abstr v 3, p 2502.

Forestier.
1861—Emploi à la mer des bois créosotés. Ann des Ponts et Chaussées ser 4, v 1, p 352-4.
1868—Mémoir sur la conservation des bois à la mer au point de vue de leur préservation contre les ravages du taret. Ann des Ponts et Chaussées ser 4, v 1, p 307-92.

Forrest, Chas. N.
1911—Characteristics of creosote and tar oils available for wood preservation. Soc Chem Ind J v 30, p 193-6, Chem Abstr v 5, p 2428-9.
1911—Creosote and tar as a preservative. Min Wld v 35, p 100.

Fox, C.
1854-5—Zincked wrought iron scupper nails for the protection of piles. Inst Civil Eng Pro v 14, p 266.

Framing timber bridge trusses before
1920 treatment. Ry Age v 68, p 1479-80.

Frankland, F. H.
1914—More about teredo-proof wood piles. Eng News v 71, p 1140.

Frary, F. C., and **Mastin,** M. G.
1913—Determination of zinc in treated ties. J Ind & Eng Chem v 5, p 738-9, Chem Abstr v 7, p 4057.

Fredendoll, P. E.
1912—Evaporation of creosote and crude oils. Eng Rec v 65, p 79-80, Chem Abstr v 6, p 924.

Fulks, E. B., and others.
1917—Report of committee on preservatives. Am Woodpreservers Assoc Pro v 13, p 256-77, Chem Abstr v 2, p 695.

Fuller, M. O.
1921—Tests of timber dock stringers. Eng News v 86, p 928.

Fumet-Dejort.
1863—Procédé de conservation des bois par le chlorure de sodium. Soc de l'Encouragement Bul v 62, p 740.

de Gemini.
1848—Moyens propres à préserver les bois des causes naturelles de l'altération. Soc de l'Encouragement Bul v 47, p 279, from Comptes Rendus.

George, John.
1829—Cause of dry rot discovered, with description of a patent invention for preserving decked vessels from dry rot, and goods on board from damage by heat. Longman, London, 186 p.

Glenn, W. H.
1898—The preservation of ties. St Ry Rev v 8, p 90-1.

Goldman, J. M.
1914-5—Preservative treatment of timber. Assoc Eng Soc J v 53, p 207-15, Coll Engr v 35, p 314-17.

Golsan, Page.
1920—Natural life of cedar poles. Elec W v 75, p 257-8.

Goltra, W. F.
1911—Concerning tie preservation. Ry & Eng Rev v 51, p 956-7.
1911—Preservation of timber; treating of cross-ties. Eng Mag v 42, p 433-6.
1911—Preservation of timber from decay. Ry & Eng Rev v 51, p 874-7.
1912—Improved method of treating ties and timbers. Ry & Eng Rev v 52, no 2, p 29-35.
1912—Some facts about treating railroad ties. Cleveland, Savage.
1913—History of wood preservation. Am Wood Preservers Assoc Pro v 9, p 178-203.
1915—Prolonging the life of poles. Wood Preserving v 2, p 49-50, Chem Abstr v 9, p 2807.
1915—Strength and quality of zinc chloride per tie or per cubic foot of timber. Am Wood Preservers Assoc Pro v 11, p 60-3, Chem Abstr v 9, p 2130.

Gosline, C. E.
1920—Catalogue of service test records of ties. Am Wood Preservers Assoc Pro v 16, p 93-148, Chem Abstr v 14, p 1024.

Goss, O. P. M.
1916—Methods of creosoting Douglas fir timbers. Am Wood Preservers Assoc Pro v 12, p 70-83, Chem Abstr v 10, p 682.

Gould, Clark W.
1914-5—Quantity of wood preservatives consumed and amount of wood treated in the U. S. in 1913-4. Am Wood Preservers Assoc Pro v 10, p 432-49, v 11, p 436-51.

Government factories for preserving
1908 wood. Harpers Weekly v 52, p 33, Apr 25.

Greeley, W. B.
1911—Timber-treating plant of the Anaconda Copper Co. Min Wld v 34, p 687-8, Chem Abstr v 5, p 2174.

Green, P. E.
1911—Notes on creosoted wood block pavements. Eng News v 65, p 474-5, Chem Abstr v 5, p 3508.

Greenberg, Morris.
1916—Experiment in the preservative treatment of fence posts. Wood preserving v 3, p 91-2, v 4, p 17-8, 42-3, 56, v 5, p 23-4, p 47-8.

Gregory, W. B.
1913—Tests of creosoted timber. Am Soc Civil Eng Trans v 76, p 1192-1203, Chem Abstr. v 7, p 2849.

Gribble or boring limnoria.
1888—Twenty-second annual report of the City Engineer of Boston, Mass. Document 38, p 40-4.

Griffin, A. E.
1910-1—Ravages of the teredo at Taikoo dock yard, Hong Kong. Inst Civil Eng Pro v 183, p 256.

Griffin, R. A.
1913—Preservative treatment of poles. Eng News v 70, p 61-2, Chem Abstr v 7, p 3213.

Grinnell, Henry.
1906—Prolonging the life of telephone poles. Yearbook of Dept Agri 1905, p 455-64.
1906—Report on the experiments of the Forest Service; seasoning, treating, and setting of telephone poles in cooperation with the American Telephone & Telegraph Co. and the Postal Cable Co., July 1, 1904, to January 1, 1906. Forest Products Laboratory Manuscript rept.

Grondal, Bror L.
1915—Preservation of log building. West Coast Lumberman v 29, no 339, p 32.
1917—Preservative treatment of poles. Washington U Forest Club Ann v 5, p 8-11.
1918—Present status of the wood preserving industry in the Pacific Northwest. Washington U Forest Club Ann v 6, p 46-8.
1918—Use of creosoted fir for marine construction. Sci Am S v 86, p 263.

Groom, Percy.
1916—Pit timber and its preservation. Coll Guard v 3, p 554-5, Iron & Coal Tr Rev v 92, p 330-1, Chem Abstr v 10, p 2039.

Guibert.
1865—Vernis pour la conservation des bois au sein de la mer. Soc de l'Encouragement Bul v 64, p 328.

Hains, Peter C.
1896—Decay of entirely submerged piles. Am Soc Civil Eng Pro v 35, p 469-70.

Halen, S.
1912—Verfahren zur behandlung des holzes mit chemikalien zum zwecke gegen die verschiedensten einflüsse beständige produkte zu erzeugen. Kunststoffe v 2, p 424-8, p 449-54, p 461-6, Chem Abstr v 7, p 692.
1913—Die in Deutschland patentierten vorrichtungen zum imprägnieren des holzes mit konservierungsmitteln und farbstofflösungen. Kunststoffe v 3, p 224-7, 267-72.

Hammersley, Hunan, R. H.
1888-9—Teredo and other timber pests. Inst Civil Eng Pro v 96, p 364-7.

Hammond, A. J.
1912—Investigation of creosoted wood block pavings after nine and one-half years of service. Eng News v 67, p 42, Chem Abstr v 6, p 924.

Handbook on wood preservation.
1916—Am Wood Preservers Assoc 73 p. Bib 56-73. Baltimore, Peters.

Hardesty, W. P.
1908—Effect of teredo in piles in Columbia river jetty work. Eng News v 60, p 109-17.

Harte, Charles R.
1919—Extending the life of wood piles. Elec Ry J v 53, p 554-9.

Hartmann, E. F.
1908—Installation of open tank for wood preservation processes. Eng News v 60, p 740-2, Chem Abstr v 4, p 3296, Am Ry Bridge & Building Assoc Pro v 18, p 234-55.

Harvey, W. H., and Co.
1906—Carbolineum treatment of timber for paving blocks. Canadian Lumberman v 26, no 5, p 30.

Haskin process of treating sleepers.
1898—Engineering v 85, p 81-4.

Hatt, W. K.
1906—Experiments on the strength of treated timber. Forest Service Circ. 39.
1911—Electrical resistance of wood treated with preservatives. Elec Wld v 57, p 828, Chem Abstr v 5, p 1875.

Haugh, James C.
1906—Inspection of treatment for the protection of timber by the injection of creosote oil. Am Soc Civil Eng Trans v 56, p 10.

Haupt, Hermann.
1872—Preservation of wood from decay. Van Nostrands Eng Mag v 6, p 481-91.

Hausser, M.
1904—Wooden sleepers or cross-ties; selection of species of timber used, and processes of preservation. Int Ry Congress Bul v 18, p 885-904.

Havelik, K.
1906—Über den wert der imprägnierung der telegraphenstangen. All Forst & Jagdz v 82, p 301-4.

Havelock, W. B.
1907—The creosoting of home-grown timber. Roy Scottish Arboriculture Soc Trans v 20, p 58-61.

Healy Tibbits construction company.
1910—Efficiency and cost of concrete for the preservation of piles exposed to sea water. Cement Rec v 4, p 16-17; Chem Abstr v 4, p 2563.

Helphenstine, P. K.
1916-9—Quantity of wood treated and preservatives used in the U. S. Am Wood Preservers Assoc Pro v 12, p 496-508, v 14, p 225-47, v 16, p 310-35.

Henry, E.
1909—Essai en grand du carbolineum avenarius. Rev d Eaux & Forêts v 48, p 204-15.
1907—Recherches sur la valeur comparative de divers produits destinés à assurer la conservation des bois. Bul d Seances de la Soc d Sci de Nancy Ser 3, v 8, no 1, p 42-139.

Herzenstein, Vladimir.
1901—On the question of the preservation of timber. Inter Ry Congress Bul v 15, p 1445-1635, 2407-30.

Hetherington, F. A.
1898—Defects of creosoted wood block pavements. Munic Eng v 15, p 137-47.

Hicks, C. S.
1918—Fireproofing and antiseptic treatment of New Zealand timbers. New Zealand J Sci v 1, p 236-46, 300-81.

Hicks, P. R.
1917—Service tests of cross-ties. Am Woodpreservers Assoc Pro v 13, p 85-228, Am Ry Eng Assoc Pro v 18, p 1291-1435, Chem Abstr v 12, p 89.
1920—Protection of piling from marine borers. Sixth inspection of San Diego, Cal. Forest Products Laboratory, manuscript rept, Project L 120.
1920—Report of the tenth inspection of treated and untreated experimental piling at Fort Mason, San Francisco, Cal. Forest Products Laboratory, manuscript rept, Project L 107.
1921—Results with butt-treated poles in California. Elec Ry J v 57, p 400.
1921—Report of the tenth inspection of treated and untreated experimental piling at San Diego, Cal. Forest Products Laboratory, manuscript rept.

Hill, Geo.
1894—Protection of piles from teredo. Am Soc Civil Eng Trans v 31, p 234.

Hill, L. L.
1920—Report of Committee No. 10 on non-pressure treatments. Am Wood Preservers Assoc Pro v 16, p 77-83, Chem Abstr v 14, p 1024.

Hodgdon, F. S.
1903—Action of sea worms on foundations in Boston harbor. Assoc Eng Soc J v 31, p 49-56.

Hopkins and **Snyder**.
1917—Damage to seasoned hard wood by lyctus beetles. Sci Am S v 83, p 246-7.

Horn, A. von.
1887—Die widerstandsfähigkeit von grünholz gegen die angriffe des pfahlwurms. Zentralblatt der Bauverwalt v 7, p 204-5.
1887—Verhalten im grünholz gegen den pfahlwurm bei wasserbauten in Holland. Zentralblatt der Bauverwalt v 7, p 279-80.

Horrocks, H. E.
1916—Pacific coast timber treating plant. Wood-preserving v 3, p 51-3.

Horton.
1882—Plan for circumventing the teredo. American naturalist v 16, p 967.

Howard, W. J.
1915—Wood block pavements with reference to economic and efficient wood preservatives. Am Soc Munic Imp Pro 1915, p 238-44, Chem Abstr v 10, p 1420.

How to increase the life of ties.
1901—Ry & Eng Rev v 41, p 618-9.

Hoxie, F. J.
1915—Treated timber for factory construction. Am Wood Preservers Assoc Pro v 11, p 215-33, Chem Abstr v 9, p 2138.
1915—Dry rot in factory timbers. Assoc Factory Mutual Fire Ins Co. (Boston, Mass.) 107 p.

Hughes, O. J. D.
1902—German tests in mine timber preserving. U. S. Daily Consular rept v 70, p 403.

Humphrey, C. J.
1915—Toxicity to fungi of various oils and salts, particularly those used in wood preservation. U. S. Dept of Agri, Bul no 227.

Humphrey, C. J., and **Fleming**, Ruth M.
1914—Toxicity of various wood preservatives. J Ind & Eng Chem v 6, p 128-31, Chem Abstr v 8, p 1336.

Hunt, Geo. M.
1915—Preservative treatment of farm timbers. Wood-Preserving v 2, p 67-8, Chem Abstr v 10, p 520.
1915—Preservative treatment of wooden silos. Wood-Preserving v 2, p 23, Chem Abstr v 9, p 1987.
1915—Temperature changes in wood under treatment. Eng Rec v 71, p 144-5, Chem Abstr v 9, p 1236, Am Woodpreservers Assoc Pro v 11, p 85-99, discussion p 100-10.
1917—Calculating the volume of poles and piles. Am Woodpreservers Assoc Pro v 13, p 245-9.
1917—Effect of soaking and subsequent air seasoning of Douglas fir upon absorption and penetration of creosote. Wood-Preserving v 4, p 50-3, Chem Abstr v 12, p 302.
1920—Brush coat should follow trimming of treated timber. Eng News v 84, p 753.
1920—Will sodium fluoride come into general use for preserving wood? Eng & Contr v 54, p 94-5, Chem & Met Eng v 23, p 1123-4.
1921—Preservative treatment of farm timbers. U S Dept Agr Farmers Bul no 744.
1923—Methods of applying wood preservatives. Lefax cir, 13-458, replacing Lefax cir 11-247.
1923—Wood preservatives. U S Dept Agr, Forest Products Laboratory, Approved copy filed April.

Hurst, J. T. ed.
1871—Principles of carpentry based upon original work of Tredgold, Spon, London, ed 3.

Hutin and **Boutigny**.
1848—Sur la conservation des bois de construction. Soc de l'Encouragement Bul v 47, p 280.

Hyde, F. W.
1920—Fence posts that do not decay. Sci Am v 123, p 63.

Impregnation of mine timber.
1914—Engineering v 97, p 602, Chem Abstr v 8, p 2470.

Impregnation of timber.
1909—Sci Am S v 67, p 162.

Increased interest in tie preservation.
1900—Ry & Eng Rev v 40, p 176-7.

Inflammability of treated and untreated
1915 wood. Lumber W Rev v 28, no 6, p 29-30.

Insect depredations in wood.
1917—Sci Am v 116, p 405.

Isaacs, John D.
1897—Preservation of structural timber. Eng News v 37, p 135-6.
1916—Vacuum process in creosoting. Am Wood Preservers Assoc Pro v 12, p 83-6, Chem Abstr v 10, p 2038.

Janka, Gabriel.
1904—Eignung des buchenholzes zu strassenpflaster im vergleiche mit nadalhölzern. All Forst & Jagdz v 80, p 321-22.

Jones, F. Meredith.
1894—Tie and timber preserving works at Las Vegas, New Mexico. Eng News v 32, p 204.

Joyce, A. R.
1917—Report of committee on specifications for the purchase and preservation of treatable timber. Am Wood Preservers Assoc Pro v 13, p 392-407.

Kansas City plant of the American Creosoting Co. Ry Age v 45, p 499-504.
1908

Karitschkoff, M.
1899—Conservation des bois par les déchets du pétrole. Soc de l'Encouragement Bul 1899, p 881-6.

Keghel, Maurice de
1912—Aging and preservation of wood. Insulated wood. Chem Abstr v 6, p 1218, 2681.

Kelleher, W. T.
1923—Lake Pontchartrain trestle. Am. Wood Preservers Assoc Pro v 19, p 30-9.

Kellogg, R. S.
1914—Protecting piling from marine borers. Southern Lumberman v 74, no 987, Aug 22, p 33.

Kemp, Harry.
1855—Conservation des bois. Soc de l'Encouragement Bul v 54, p 310; from Newton's London Journal.

Kempfer, W. H.
1911—Preservative treatment of poles. Forest Service Bul no 84, Chem Abstr v 5, p 2721.

Kendrick, J. W.
1905—Ties and tie preservation. Ry Age v 39, p 52, 63-4, 150-3.
1905—Tie preservation. Ry & Eng Rev v 45, p 327-8.
1905—Wooden sleepers or cross-ties; selection of species of timber used and processes of preservation. Inter Ry Congress Bul v 19, p 31-94.

Kern, M. G., and others.
1887—Report on the relation of railroads to forest supplies and forestry, together with appendices on the structure of some timber ties, their behavior and the cause of their decay in the road-bed; on wood preservation; on metal ties and on the use of spark arresters. Forest Service Bul no 1, 149 p.

Kerr, George L.
1900—Preservation of timber. Practical Coal Mining, p 177-9. London, Griffin, 462 p.

Kitchin, Paul C.
1918—The relation between the structures of some coniferous woods and their penetration by preservatives. Michigan Acad Sci Ann rept v 20, p 203-21.

Knight, N.
1909—A wood preservative. J Ind Eng Chem v 1, p 260, Chem Abstr v 3, p 2380.

Knowlton, H. H.
1906—Timber creosoting plant at Shirley, Ind. Eng News v 56, p 267-8.

Koller, Theodor.
1896—Imprägnierungs-technik. Handbuch der darstellung aller fäulnisswiderstehenden, wasserdichten und feuersicheren stoffe für techniker fabrikanten und industrielle. Vienna, Hartleben.

Krause, Max.
1898—Ueber das Hasselmannsche imprägnierungs verfahren, speziell in seiner bedeutung für das grubenholz. Glückauf v 34, p 760-4, Coll Guard v 56, p 1013.

Kroemer, F. W.
1909—Test of preservative penetration. Wood-Preserving v 5, p 18-21, Chem Abstr v 12, p 1695.

Keuhn, A. L.
1911—Wood preservation. Canadian Eng v 20, p 430-2, Chem Abstr v 5, p 2174.
1917—Report of committee on plant operation. Am Wood Preservers Assoc Pro v 13, p 240-1, Chem Abstr v 11, p 697.

Kummer, F. A.
1900—Proposed method for the preservation of timber. Am Soc Civil Eng Pro v 44, p 181-219, abstr Eng News v 43, p 378-9.

Labrot, S. W.
1903—Notes on the treatment of timber. Ry & Eng Rev v 43, p 309-10.

Lamb, R., and **Schreiber,** J. M.
1911—Timber preservation, its development and present scope. Am Soc Civil Eng Pro v 37, p 141-51.

Lantier, M. F.
1907—Nouveau procédé d'injection des bois. (système Rüping). Rev Gen des Chemins de Fer v 30, pt 2, p 238-49.

Larkin, A. E.
1916—Discussion on preservative specifications for wood paving blocks. Am Wood Preservers Assoc Pro v 12, p 148-54, Chem Abstr v 10, p 2039.

Laslett, Thomas.
1894—On the seasoning and preservation of timber, p 73-90. Timber & Timber Trees, London, Macmillan, 442 p.

Laurent, L.
1850—Recherches et résultats d'observations des moeurs des animaux nuisibles aux grands approvisionnements de bois de marine. Comptes Rendus v 31, p 74-8.

Leavitt, W. M.
1920—Pole preservation. Elec J v 45, p 321-2.
1921—Butt treatment of cedar poles by open tank method. Elec Rec v 78, p 403-4.

Lee, Laurence.
1921—Prolonging the life of farm timbers. N. Y. State Col Forestry, Syracuse U Cir no 34, 22 p.

Leger and **Perronet.**
1858—Emploi du sulfate de cuivre pour la conservation des bois. Soc de l'Encouragement Bul v 57, p 746-7; from Soc Ing Civil.

Legros, P.
1855—Conservation des bois. Soc de l'Encouragement Bul v 54, p 440-1.

Lemaire, E.
1907—Conservation des bois par les nouvelles méthodes d'imprégnation. Génie Civil v 50, p 403-6.
1908—Valeur comparative des antiseptiques employés pour la préservation des bois. Génie Civil v 53, p 351-4.

Lengny, G.
1900—Sénilisation rapide et l'ignifugation des bois par l'électricité. Rev Technique v 21, p 245-50.

Leven, George.
1904—Creosoting timber for estate purposes. Roy Scottish Arboricultural Soc Trans v 17, p 93-6.

Lewis, H. W.
1866—Preservation of wood in damp and wet situations. J Frank Inst v 81, p 217-23, 289-95.

Lewis, R. G.
1913—Preservative treatment of fence posts. Canada Dept Int Forestry Branch Circ no 6.

Light creosote oils in wood preservation. 1920—Eng & Contr v 53, p 722, Chem & Met Eng v 23, p 56.

Limnoria lignorum und andere holzzer-1868 störer an den Nordsseeküsten. Centralblatt der Bauverwalt v 6, p 266.

Lindsey, J. B., jr.
1906—Inspection of treatment for the protection of timber by the injection of creosote oil. Am Soc Civil Eng Pro v 32, p 148-53.

Lingard, J.
1827—Philosophic and practical inquiry into the nature and constitution of timber; including an investigation into the causes of dry rot, and a proposal for effectually preserving timber against premature decay. 2nd edition (London) Longman.

Locust Point pier collapse in Baltimore. 1907—Eng News v 58, p 134-5.

Long life for creosoted piles in railroad 1920 trestle. Ry Age v 68, p 247-9, Chem Abstr v 14, p 2066.

Ludlow, William.
1881—Report relating to the use of creosote for protecting submerged timber. Delaware Breakwater Harbor. U S Ann Rept Chief of Engrs U S Army Appendix F, p 818-9.

McBee, E.
1909—Plea for wood preserving process. Eng News v 61, p 108.

McDonald, G. B.
1912—Methods for the preservation of mine timbers. Min & Eng Wld v 36, p 1049-50, Chem Abstr v 6, p 2993.
1915—Preservative treatment of fence posts. Iowa State Col Agr & Mech Arts Bul no 158, 150 p; Chem Abstr v 10, p 1088.

McKenzie, Wm. B.
1906—Creosoting timber. Reprinted from Canadian Eng, 14 p.

McLean, J. D.
1917—Protection of piling from marine borers; progress report no. 9. Treatment of piling specimens with six different coal tar creosotes. Forest Products Laboratory manuscript rept., project 120.
1919—Report of seventh inspection of treated piling specimens on the Gulf Coast. Forest Products Laboratory manuscript rept, project L 120.
1920—Report of eighth inspection of treated piling specimens on the Gulf Coast. Forest Products Laboratory manuscript rept, project L 120.
1922—Report of ninth inspection of treated piling specimens on the Gulf Coast. Forest Products Laboratory manuscript rept, project L 120.
1923—Report of tenth inspection of treated piling specimens on the Gulf Coast. Forest Products Laboratory manuscript rept, project L 120.
1924—Results of treatment of piling specimens against attack by marine borers. Forest Products Laboratory. Reprint from Eng & Contr Railways issue March 1924.

McNeil, J. E.
1902—Improvement in the use of ties. Ry & Eng Rev v 43, p 706.

MacFarland, H. B.
1912—Test of the strength of creosoted bridge timber. Eng News v 68, p 1035, Chem Abstr v 7, p 545.
1914—Effect of creosoting on strength of Oregon fir piling. Eng News v 72, p 863, Chem Abstr v 9, p 140.
1914—Effect of steaming process of creosoting on strength of Oregon fir piling. Eng Rec v 70, p 487-8.
1915—Tests of Oregon fir piling. Am Ry Eng Assoc Pro v 16, pt 2, p 47-150, Chem Abstr v 10, p 262.
1916—Tests of Douglas fir bridge stringers (to determine the effect of treatment on strength). Am Ry Eng Assoc Bul 184, pt 2, p 281-467, Chem Abstr v 10, p 1259.

Malenkovic, Basilius.
1906—Neure ergebnisse in der bekämpfung der im hochbau auftretenden holzzerstörenden pilze. Zeit d oesterr Ing Arch Ver v 58, p 81-4.
1907—Holzkonservierung im hochbaue mit besonderer rücksichtnahme auf die bekämpfung des hausschwammes. Vienna A. Hartleben.
1914—Zukunft der holzkonservierung mit wasserlöslichen stoffen. Zeit angew Chem v 27, p 132-5, Chem Abstr v 8, p 2470.

Mann, J. C.
1910—Testing of coaltar creosote. Soc Chem Ind J v 29, p 732-5, Chem Abstr v 5, p 991.

Manterola, J. P.
1916—Observaciones sobre el ataque de las maderas por el taret en la bahia de Valparaiso. Ann Inst de Ing de Chile v 16, p 413-16.

Marechal.
1863—Procédés de durcissement et d'imperméabilisation du bois. Soc de l'Encouragement Bul v 62, p 252.

Margery, L.
1841—Procédé propre à garantir de toute altération les matières végétales et animales. Soc de l'Encouragement Bul v 40, p 209-10.

Martin, Robert.
1895-6—Treatment of timber for use in mines. Min Inst Scotland Trans v 17, p 69-74, Fed Inst Min Eng Trans v 10, p 531-6.

Mason, T. H.
1908—Preservation of timber. Min & Sci Pr v 97, p 37-41.

Mathers, F. C., and **Moncreiff,** J. N.
1913—Preservation treatment of wood with water-gas tar. Gas Age v 31, p 393, Chem Abstr v 7, p 1963.

Mattoon, W. R.
1920—Treating fence posts on farms. Louisiana State U Ext Div Circ no 37, 20 p.

Mattos, F. D., and **Blake,** E. M.
1920—Report on creosoted piling removed from Long Wharf, Oakland, Cal. Am Woodpreservers Assoc Pro v 16, p 148-78.

Mayer, Adlof Eduard.
1872—Chemische technologie des holzes als baumaterial. Braunschweig, F. Viewegund Sohn.

Meier, H.
1862—Die Pfahlmuschel. Aus der Heimat col. 149-56, 173-6.

Meigs, M.
1911—Experiment in wood preservation. Prof Mem Eng Corps U S Army v 3, p 231-5.

Mell, C. D., and **Brush,** W. D.
1913—Greenheart. Forest Service Cir no 211.

Melsens.
1865—Sur la conservation des bois. Soc de l'Encouragement Bul v 64, p 28-34.

Meredith, Mark.
1917—Common salt for preserving wood. Machinery v 23, p 586, Chem Abstr v 11, p 1030.

Merklen, J. M.
1905—Creosoting works of the Western Central Railway of France. Eng News v 54, p 87-8.

Method of preserving railroad timbers. 1903 Am Lumberman Mar 21, p 25.

Methods of increasing durability of 1907 wood. Canadian Lumberman v 27, no 5, p 19.

Meyer, Herbert W.
1917—Prolonging the existence of cedar poles. Elec Wld v 70, p 610-11.

Milburn, H. W.
1912—Effect of creosote oil on bituminous fillers for creosoted wood block. Munic Eng v 43, p 109, Chem Abstr v 6, p 2512.

Millet.
1847—Dessication de bois, procédé de M. Millet. Soc de l'Encouragement Bul v 46, p 436-7.

Mitchell, W. G.
1915—Treated wood block paving. Can Dept Interior Forestry Branch Bul no 49, bibliography p 40.

1916—Experimental wood preserving laboratory. Wood Preserving v 3, p 33-5, Chem Abstr v 10, p 2039.

1916—Preservative treatment of timber. Canadian Lumberman v 36, no 12, p 34-7.

Modern preservation of railroad ties. 1905 Sci Am v 93, p 414-5.

Moll, F.
1912—Preservation of posts. Chimiste v 2, p 306-9, Chem Abstr v 6, p 1667, from.

1913—Kunstliche schutz des holzes durch ätzsublimat (Kyanisierung). Zeit Angew Chem v 26, p 459-63.

1913—Physikalische und chemische eigenschaften der zur holzkonservierung angewandten teere und teerderivate. Zeit angew Chem v 26, p 792-800, Chem Abstr v 8, p 3623.

1914—The ship-worm (Genus Teredo Linne) from Naturwissenschaftliche Zeitschrift für Forst-und Landwirtschaft, v 12, p 505-64.

1914—Einrichtung und betrieb von anstalten zum imprägnieren von holz unter druck mit antiseptischen flüssigkeiten. Chemische App v 1, p 49-52, 101-3, Chem Abstr v 8, p 2237.

1914—Preservation of wood by means of corrosive sublimate. Am Wood Preservers Assoc Pro v 10, p 236-49, Chem Abstr v 8, p 2934.

1915—Artificial preservation of mine timbers. Forestry Q v 13, p 308-16.

1915—Beitrage zur frage der giftgefahr durch die zur holzkonservierung benutzten stoffe. Zeit angew Chem v 28, p 73-5, Chem Abstr v 9, p 486, 1237.

1915—Entwicklung und der gegenwärtige stand der holzimprägnierung mit salzen. Zeit angew Chem v 28, p 317-22, 328-31, Chem Abstr v 9, p 2580.

1915—Imprägnierung des Holzes nach dem Verfahren des Dr. Boucherie. Chemische App v 2, p 49-53, 63-67, Chem Abstr v 9, p 1381.

1915—Schutz des holzes gegen fäulnis durch anstriche und ueberzüge. Kunststoffe v 5, p 169-71, 182-5, 210-2, 219-22, Chem Abstr v 10, p 108.

1916—Bibliography of wood-boring crustaceans. Am Woodpreservers Assoc Pro v 12, p 409-13.

1916—Über die Verwendung ammoniakalischer Salslösungen zur Holzkonsevierung. Zeit angew Chem v 29, part 1, p 339-41, Chem Abstr v 11, p 1284.

1917—Gegenwartige stand der imprägnierung von holzmasten. Elektrotech Zeit v 38, p 270-1, Chem Abstr v 12, p 756-7.

1918—Influence of the war on the preservative treatment of wood. Zeit angew Chem v 31, p 224, Chem Abstr v 14, p 108.

1920—Salt mixtures as preservatives for wood against fungus and decay. Zeit angew Chem v 33, p 39-40, Chem Abstr v 14, p 2066.

Montfort, R.
1894—Protecting piles against the teredo navalis on the Louisville and Nashville Railroad. Am Soc Civil Eng Trans v 31, p 220-33.

Montpellier, J. A.
1899—Sénilisation rapide des bois par l'électricité. Electricien v 18, p 237, 255-8.

Moore, W. E.
1902—Does it pay to creosote wooden poles for electric line work? Elec Rev v 40, p 708-9.

More soda treatment of sap timber;
1909 steaming of timbers. Southern Lumberman v 58, no 696, p 29.

Moreau, Aug.
1911—Sur l'antiseptique le "microsol." Soc de l'Encouragement Bul v 115, p 613-27, Chem Abstr v 5, p 2926.

Müller, J.
1868—Ueber die mittel, das zu seeschiffen und wasserbauten zu verwendende holz gegen die zerstörung des holzwurms zu bewahren. Poly Notizblatt v 23, p 113-21.

Nansouty.
1885—Mangeurs des pilotis. Génie Civil v 7, p 308-9.

Neale, R. E.
1913—Powell saccharine process for seasoning and preserving timber. Elec Rev (London) v 73, p 444-5, Chem Abstr v 8, p 230.
1913—Saccharine timber preservative; equipment, operation and efficiency of the Powell seasoning process. Eng Mag v 46, p 437-9.

Nelson, John M.
1906—New timber preservative. Ry & Eng Rev v 46, p 341.
1907—New wood preservative. Ry & Eng Rev v 47, p 633.
1907—Preservation of mine timber. Min Wld v 26, p 656-7.
1907—Prolonging the life of mine timbers. Forest Cir no 111, 22 p.
1909—Preservation of mine timbers. Eng & Min J v 88, p 211-2.

New concrete covering for timber piles
1906 in teredo infested waters. Eng News v 55, p 21-2.

New process of timber treatment. Eng
1912 News v 68, p 954, Chem Abstr v 7, p 238.

New process of wood seasoning. En-
1912 gineering v 113, p 463, Chem Abstr v 6, p 2159.

New specifications of the board of local
1912 improvements of Chicago for creosoted wood block pavements. Eng & Contr v 38, p 68, Chem Abstr v 6, p 2512.

New tie and timber preserving plant of
1906 the Atchison, Topeka and Santa Fe Railway at Somerville, Tex. Eng News v 55, p 490-3.

New tie treating plants on the Rock
1908 Island lines. Ry & Eng Rev v 48, p 391-2.

Newton, H. M., **Church,** S. R., and **Schrenk,** H. von.
1915—Specifications for wood paving block oil. Wood preserving v 2, p 44, Chem Abstr v 9, p 2702.

Norfolk Creosoting Company. Creosoted
1900 timber; its preparation and uses. Philadelphia, Heywoods.

Nowotny, R.
1907—Zur frage der holzkonservierung im telegraphenlinienbaue. Baumaterialienkunde v 12, p 65-9.
1911—Ueber den wert von laboratoriumsversuchen für die holzimprägnierung. Zeit angew Chem v 24, p 923-8, Chem Abstr v 5, p 2720.
1912—Preservation of wood with "Bellit." J Ind & Eng Chem v 4, p 542, Chem Abstr v 6, p 2681, from Oesterr Chem Zeit.
1912—Ueber die voraussichtliche lebensdauer imprägnierter holzmasten. Elektrotech Zeit v 33, p 976-9.
1913—Erfahrungen aus der praxis der holzimprägnierung mit fluoriden. Zeit angew Chem v 26, p 694-700, Chem Abstr v 8, p 1003.
1917—Impregnation of wood with mercuric chloride solution. Soc Chem Ind J v 36, p 880, Chem Abstr v 12, p 89.
1919—Impregnation of wood with limited amounts of mercuric chloride. Soc Chem Ind J v 38, p 502A, Chem Abstr v 12, p 89, v 13, p 2987.
1919—Über gesetzmäszige aufnahmen von imprägniermitteln bei leitungemasten. Elektrotech und Maschinenbau v 37, p 105-08, Chem Abstr v 13, p 2749.
1921—Basilit: a preservative for wooden poles. Elec W v 77, p 722, from Telegraphen u Fernsprechtechnik.

Noyon.
1859—Sur l'inefficacité de l'injection par le procédé Boucherie pour la conservation des bois employés à la mer. Ann des Ponts et Chaussées ser 3, v 17, p 236-41.

Oakes, John C.
1909—Creosoted and creosoting. Prof Mem Eng Corps U S Army v 1, p 108-39.

Old Dominion Creosoting Works.
1906—Preserving timber. Mfg Rec v 49, no 1, p 12.

Olwares, J. de.
1909—Safeguarding wood against ants. U S Daily Consular repts Feb 11, no 3404, p 13.

Park, E. S., and **Weber,** J. M.
1920—Processes and equipment used in wood preservation. Ry Rev v 67, p 972-5, Mech Eng v 43, p 98-9.

Parker, J. F.
1907—Preservatives for wood and metal. Ry Age v 44, p 544.
1913—Treated versus untreated ties. Eng Mag v 45, p 741-4.

Paeleorms og Paelekrebs Angreb Ved
1921 Skandinaviens Kyster. Betaenkning. Ingenioren v 30, p 287-304.

Paton, J.
1849—Southend timber pier. Inst Civil Eng Pro v 9, p 23-57.

Payen.
1840—Procédé de conservation de bois. Soc de l'Encouragement Bul v 39, p 20-1.

1841—Conservation de bois, essais et expérience. Soc de l'Encouragement Bul v 40, p 130.

1841—Conservation de bois, procédé de M. Bréant. Soc de l'Encouragement Bul v 40 p 20-2.

1849—Conservation de bois, procédé de Périn. Soc de l'Encouragement Bul v 48, p 51.

Payne.
1847—Conservation de bois, procédé de Payne. Soc de l'Encouragement Bul v 46, p 703.

1861—Mémoire sur la conservation des bois. Ann du Conservatoire Arts & Métiers v 1, p 692-732.

Pearson, R. S.
1918—Further note on the antiseptic treatment of timber, recording results obtained from past experiments. Calcutta. 128 p; J of Forestry v 17, p 190-1, p 718; Chem Abstr v 13, p 504.

Perlewitz, K.
1910—Konservierung hölzerner maste für elektrische leitungen. Elektrotech Zeit v 31, p 913-5, Chem Abstr v 5, p 194.

Perten, J.
1909—New process of impregnating wood. Soc Chem Ind J v 28, p 711, Chem Abstr v 5, p 194.

1911—Bekämpfung von hausschwamm und trockenfäulè. Chem Zeit v 35, p 310, Chem Abstr v 5, p 2174.

Peters, Evelyn Willing.
1912—Preservation of mine timbers. Forest Service Bul no 107.

Petritsch, E. F.
1907—Beitrag zur frage der konservierung hölzerner leitungmaster. Maschinenbau v 25, p 193-7.

Portable plant for the preservation of
1899 railway ties. Eng News, v 42, p 108.

Port Reading creosoting plant.
1915—Wood-preserving v 2, p 37-40, Chem Abstr v 9, p 2703.

Powell, E. L.
1914—Timber conservation and preservation. Assoc Eng Soc Pro v 52, p 260-7, Inst Civil Eng Pro v 198, p 357.

1914—Treatment of piling and timber according to conditions of use and exposure. Am Woodpreservers Assoc Pro v 10, p 280-2.

Powell process of preserving timber.
1904—Eng News v 52, p 473.

Powellsche verfahren zur konservierung
1907 von Holz mittolst zucker, Baumaterialienkunde v 12, p 268-70, Sci Am S v 63, p 26216-7.

Powell wood process.
1907—Canadian Lumberman v 27, no 9, p 17.

Praille, G. de la.
1916—Preservation of wood. Chem Abstr v 10, p 1419, p 1920.

Preliminary report on preservation of
1882 timber. Am Soc Civil Eng Trans v 11, p 325-44.

Present condition of timber preserving
1902 in the United States. Railroad Gaz v 34, p 618-9.

Preservation of mine timbers from de-
1907 cay. Mines & Min v 27, p 460-1.

Preservation of mine timbers.
1909—Min Wld v 30, p 343-4.

Preservation of mine timber.
1919—Coal Age v 16, p 164, 377-8, 459, 760.

Preservation of outdoor timber.
1914—Gt Brit Bd Agr & Fisheries London 4 p Leaflet no 284.

Preservation of ties in France.
1895—Ry Gaz v 27, p 218.

Preservation of ties on the Southern
1900 Pacific Railway. Eng News v 44, p 278-9.

Preservation of timber.
1907—Sci Am S, v 64, p 71-2.

Preservation of timber; report of the
1885 committee on the preservation of timber, presented and accepted at the Annual Convention, June 25, 1885. Am Soc Civil Eng Trans v 14, p 247-398.

Preservation of timber; some new data
1907 on penetration. Sci Am S v 64, p 71-2.

Preservation of timber; standing sub-
1908 ject no 5. Am Ry Bridge & Bldg Assoc Pro v 18, p 256-70.

Preservation of timber from boring or-
1917 ganisms. Engineering v 103, p 174.

Preservation of wood.
1903—Sci Am S, v 56, p 23075, from La Chronique Industrielle.

Preservation of wood by "Aczol"
1911—Chem Abstr v 5, p 381, from Le Chimiste.

Preservation of wood by the Powell
1913 process. Canadian Eng v 24, p 155, Chem Abstr v 7, p 1088.

Preservation for wood and metal.
1907—Assoc Ry Superintendents of Bridges and Bldgs Pro v 17, p 141-54.

Preservative against wood splitting.
1907—Timber Tr J v 62, p 727.

Preservative agents on mine timber, On
1890-1 the effects of. Inst Civil Eng Pro v 104, p 394-5.

Preservative treatment of wood poles.
1921—Pub Works v 50, p 63.

Preservative treatment of yellow pine.
1909—Eng Dig v 6, p 220, Chem Abstr v 3, p 2751.

Preserve the pole line.
1921—Elec Ry J v 57, p 126.

Preserving methods for ties.
1902—Ry & Eng Rev v 42, p 303-4, 383, 425, 609, 658-9.

Preserving of timber, a statement of re-
1900 cent suggestions regarding the methods of preserving timber and a hint concerning the reason that treated timber ties last longer in Europe than in U. S. Eng Rec v 42, p 145.

Preserving timber, final report of com-
1885 mittee. Am Soc Civil Eng Trans v 14, p 247-398.

Preserving timber with woodiline.
1896—Ry Gaz v 28, p 60-1.

Preserving wood roof timbers.
1921—Textile Wld v 59, p 215, 217.

Prince, R. E.
1914—Preliminary work in fire-proofing wood. Am Woodpreservers Assoc Pro v 10, p 158-74, Chem Abstr v 8, p 2934.

Prindle, F. C.
1890—Wood treatment tests. Eng News v 23, p 159, Elec W v 15, p 176.

Procédé de conservation des bois em-
1853 ployé sur les chemins de fer. Soc de l'Encouragement Bul v 52, p 82-5.

Protecting piles from the teredo.
1906—Railroad Gaz v 41, p 137-8.

Protecting piles from the teredo.
1918—Sci Am v 119, p 128.

Protection of piles against teredo.
1895—Ry Rev v 35, p 636.

Protection of piles against teredo. L. &
1893 N. R.R. Eng News v 30, p 319-20.

Protection of piles by gunite.
1922—Canadian Eng v 42, p 559.

Protection of piles in water infested by
1921 marine borers; report of subcommittee. Am Ry Eng Assoc Bul 233, p 472-9.

Puncturing poles before impregnation.
1921—Elect Ry J v 57, p 560.

Purse, D. G.
1907—Relief for lumber situation; vulcanizing to improve the character of timber. Mfg Rec v 52, no 16, p 54-5.

Putman, W.
1910—Failure of wooden piling due to private agencies and methods of protection. Canadian Eng v 18, p 393-5.

Putnam, J. W.
1880—Preservation of timber. Am Soc Civil Eng Trans v 9, p 206.

Quatrefages.
1848—Moyen de préserver les approvisionnements de bois de la marine de la piqûre des tarets. Soc de l'Encouragement Bul v 47, p 280.

Radford, H. V.
1904-6—Artificial preservation of timber. N Y Forest Fish & Game Commission 10-12 Ann rept p 345-59.

Railway tie question; gives abstracts of
1903 reports, addresses and discussion of this subject at the recent convention of the Roadmasters and Maintenance of Way Association in Kansas City. Eng News v 50, p 463-5.

Rawson, Ralph H.
1920—Penetration of creosote in various sizes of sawed lumber and round piling. Am Wood Preservers Assoc Pro v 16, p 74-83, Chem Abstr v 14, p 1024.

Recent developments in wood preserva-
1921 tion. Eng News v 86, p 297-9.

Record of treated ties, Atchison, Topeka
1905 and Santa Fe Railway. 1885-1904. Ry & Eng Rev v 45, p 137.

Reilly, P. C.
1914—Creosote oil. Am Wood Preservers Assoc Pro v 10, p 84-8, Chem Abstr v 8, p 2934.
1915—Proper oil for treating creosoted wood blocks for paving. Am Soc Munic Impr Pro 1915, p 210-37, Chem Abstr v 10, p 1420.
1915—Specification for a coal-tar creosote solution. Am Woodpreservers Assoc Pro v 11, p 158-68, Chem Abstr v 9, p 2138.
1918—Destruction of wood block pavement due to use of tar in the creosote oil. Munic Eng v 54, p 183-4, J Forestry v 16, p 826-7.

Report of Committee on preservatives.
1914—Am Woodpreservers Assoc Pro v 10. p 58, Chem Abstr v 8, p 2933.

Report of Committee on preservative
1911 treatment of poles and crossarms. Nat Elec Light Assoc v 41, p 579-700.

Report of Committee on specifications
1916 for the purchase and preservation of treatable timber. Am Woodpreservers Assoc Pro v 12, p 171-87.

Report of Committee on wood preserva-
1920 tion. Railway Age, v 68, p 924-8.

Report of Committee XVII—Wood Pres-
1919 ervation. Am Ry Eng Assoc Bul v 21, no 222, p 295-337.

Report of Marine Piling Committee.
1923 N. R. C. in cooperation with Committee on wood preservation A. R. E. A. Am Ry Eng Assoc Bul no 255, p 959-64.

Report of San Francisco Bay Marine
1921 Piling Committee. Eng News-Rec v 86, p 471-2.

Report on the abuse of treated materi-
1920 als. Ry Age v 69, p 759-60, Eng & Contr v 54, p 509.

Reports of creosoted piling in Galveston
1914 Bay bridge of Santa Fe Railway. Report on piling in water 38 years. Am Wood Preservers Assoc Pro v 10, p 112-94.

Resistance des pieux créosotés ou
1922 cuivrés aux attaques du teredo. Génie Civil v 80, p 414.

Review of the railway tie question.
1903—Eng News v 50, p 223-5.

Rex, Geo. F.
1920—Catalogue of service test records of ties. Report of committee on service records. Am Wood Preservers Assoc Pro v 16, p 146.

Rhodes, F. L., and **Hosford,** R. F.
1915—Recent results obtained from the preservative treatment of telephone poles. Am Inst Elec Eng Pro v 34, p 2343-87, Chem Abstr v 10, p 108.

Richards, C. Audrey.
1923—Methods of testing the relative toxicity of wood preservatives. Am Wood Preservers Assoc Pro v 19, p 127-35.

Ridgeway, F. B.
1914—Creosoted piling in Galveston Bay bridge. Eng News v 71, p 1176-82.

Rivierre et Arnoux.
1871—Sur le créosotage des bois au port de Trouville. Ann des Ponts et Chaussées 1871, p 293-305.

Roach, D. E.
1906—Creosoted piles. Ry Age v 41, p 885.

Rockwell, D. A.
1907—Preservative treatment of poles by the open tank process. Elec W v 50, p 1170-2.

Rodd Company.
1919—Preservation of wood. Pittsburgh, Pa. 48 pp.

Rollins, H. M.
1915—Report of committee on plant operation. Am Wood Preservers Assoc Pro v 11, p 43-7.

Rottier.
1875—Use of copper salts for preserving wood. J Frank Inst v 99, p 234-6, from Rev Industrielle.
1877—Preservation of timber with salts of copper. Van Nostrand's Eng Mag v 16, p 35-9, from Engineering.

Rowe, Samuel M.
1899—Preservation of timber. W Soc Eng J v 4, p 283-7.
1907—Present outlook for railway tie preserving processes in the U. S. Eng News v 57, p 63-4.
1908—Preservation of railway ties. Ry Age v 45, p 698-700.
1908—Proper methods of treating timber. Eng News v 60, p 20.

Sackett, H. S.
1911—Consumption of wood preservatives and quantity of wood treated in the U. S. in 1910. Forest Service Cir no 186, Chem Abstr v 6, p 540.

Sadtler, Samuel P.
1904—Preservative treatment of wood. Tech Q v 17, p 129-44.

Saline solution treatment to prevent sap 1908 stain in red gum. Southern Lumberman v 56, July 18, p 27

Scammell, Edward Thomas.
1903-4—Preservation of timber, with special reference to its protection from dry rot and the increase of its usefulness for estate fencing and other purposes. Surveyors Inst Trans v 36, p 69-93, discussion p 93-112.

Schaekell, L. F.
1915—Comparative toxicity of coal tar creosote and creosote distillates and of individual constituents for the marine woodborer, Xylotrya. Am Woodpreservers Assoc Pro v 11, p 233-47, Chem Abstr v 9, p 704.
1916—Marine Borers from the wood preservers' standpoint. Am Woodpreservers Assoc Pro v 12, p 124-31, Ry Age Gaz v 60, p 508-10, Chem Abstr v 10, p 2038.
1919—Surface tension of wood preserving oils as factors in protection against marine borers. Am Woodpreservers Assoc Pro v 15, p 113-23.

Schaffnit, E.
1911—Zur beurteilung und bekämpfung von hausschwamm und trockenfäuleschäden nach neueren gesichtspunkten. Chem Zeit v 35, p 253-4.

Schiffsbohrwurm Europa's.
1866—Ausland v 39, p 392-5.

Schlauf.
1912—Kyan's Process and its sanitary importance. Chem Abstr v 6, p 2159.

Schmidt, J.
1919-20—Ueber freileitungsmasten und mittel zur erhöhrung ihrer lebensdauer. Elektrotech Anzeiger v 36, p 353-4. v 37, p 289-90, 295-6, 319-20, 323-4, 339-40, 345-6.

Schneidt, A.
1897—Tränkung der hölzernen eisenbahnschwellen mit chlorzink und mit karbolsäuerehaltigem theeröle. Organ f d Fortsch d Eisenbahnw v 34, p 75-80, 92-7.

Schoch, E. P.
1908—Economics of wood preservation. Eng Mag v 35, p 607-9.
1908—Review of the present practice and economics of timber preservation. Elec Ry Rev v 19, p 555, 568-70.
1914—Toxicity of various wood preservatives. J Ind Eng Chem v 6, p 603-4.

Schutz der wasserbauhölzer.
1914—Holzwelt v 1, p 13-4, March 27.

Science of wood preservation.
1903—Am Lumberman, Oct. 31, p 44-6.

Seasoning and preserving ties.
1903—Am Lumberman, Sept. 12, p 16.

Seidenschnur, F.
1901—Okonomische tränkung von holz mit theeröl. Zeit Angew Chem v 14, p 437-41, 488-95.
1906—Ueber die imprägnierung von grubenhölzern. Glückauf v 42, p 560-3.
1909—Zur frage der holzkonservierung. Chem Zeit v 33, p 701-2.

Service tests of treated and untreated 1917 posts of various species. Am Woodpreservers Assoc Pro v 13, p 229-34.

Sharp, Wm.
1887-8—Creosoting timber in New Zealand. Inst Civil Eng Pro v 93, p 408-20.

Sherfesee, W. F.
1908—Preservative treatment of loblolly pine cross arms. Forest Service Cir no 151.
1908—Primer of wood preservation. Forest Service Cir no 139.
1908—Seasoning and preservative treatment of hemlock and tamarack cross-ties. Forest Service Cir no 132.
1908—Wood preservation. Sci Am S v 66, p 78-80.
1908—Wood preservatives and processes in the U. S. J Elec Power & Gas v 21, p 317.
1908—Wood preservation in the U. S. Forest Service Bul no 78.
1909—Open-tank process of timber preservation. Eng Mag v 37, p 435-8.

1909—Relation of non-pressure processes of wood preservation to pressure processes. Eng News v 61, p 230-2, Chem Abstr v 4, p 1804.

Shimek, B.
1907—Wood preservation. Wood Craft v 6, p 153-6.

Shipley, G. B.
1906—Santa Fe's modern timber treating plant at Somerville. Ry Age v 41, p 425-31.
1909—Comparison of the various processes of preserving timber. Eng News v 62, p 396-400.
1910—Cost of timber preservation. Eng Mag v 38, p 599-602.
1910—New timber treating plant of the Eppinger and Russell Co., Jacksonville, Fla. Eng News v 63, p 545-7, Chem Abstr v 4, p 2043.

Shirley Plant of the Columbia Creosot-
1906 ing Co. Railroad Gaz v 40, p 282-4.

Smart, V. I.
1905—Rail circuits and zinc treated ties. Railroad Gaz v 38, p 277-8.

Smith, C. G.
1875—Pine timber. Engineering v 19, p 351-2, 392-3.

Smith, C. Stowell.
1908—Preservation of piling against marine wood borers. Forest Service Cir no 128. Eng & Contr v 53, p 91.
1908—Seasoning and preservative treatment of arborvitae poles. Forest Service Cir no 136.

Smith, E. R.
1900—Some notes of an experience with teredo navalis. Eng News v 43, p 361.

Smith, Lowry.
1916—Penetration of preservatives. Ry Maintenance Engr v 12, p 173-4, Wood-Preserving v 3, p 66-8, Chem Abstr v 10, p 2512.
1920—Wood preservation. Boston Soc Civil Eng J v 7, p 127-35.

Snow, Chas. H.
1898—Marine wood borers. Am Soc Civil Eng Trans v 40, p 178-214.

Snyder, Thomas E.
1912—Insect damage to mine props and methods of preventing the injury. U S Bureau of Entomology Cir no 156, 4 p.
1919—White-ant-proof wood for the tropics. Am Lumberman no 2324, 58.

Sodium Fluoride as a wood preservative.
1920—Eng News v 84, p 1253.

Sodium Fluoride as a preservative.
1920—Ry Maintenance Eng v 16, p 142. Chem Abstr v 14, p 2066.

Some European methods of preserva-
1900 tion. Ry & Eng Rev v 40, p 243-4; 432-3.

Special forms for jacketing wood piles
1917 with concrete. Eng News v 77, p 283.

Specifications for creosoting Oregon fir
1907 piling and bridge timber. Ry & Eng Rev v 47, p 823-4.

Specifications for the preservative treat-
1920 ment of wood. Boston Soc Civil Eng J v 7, p 136-44.

Spofford, C. M.
1917—Zinc chloride as a preservative of structural timber. Nat Assoc Cotton Mfg. Trans. no 102 p 236-41 Chem Abstr v 12, p 2047.

Spring, F. J.
1904—Report on the question of wooden sleepers or cross-ties. Int Ry Congress Bul v 18, p 777-840.

Springer, J. F.
1921—Enemies of timber construction. Sci Am v 125, p 118, 123-4.

Standage, H. C.
1902—Preservative processes for woodwork. Builder v 82, p 372-4.

Standard specifications for creosoted
1923 piling for Atlantic coast waters adopted. Wood-preserving News v 1, p 46-9.

Stanford, H. R.
1906—Inspection of treatment for the protection of timber by the injection of creosote oil. Am Soc Civil Eng Trans v 56, p 1-9.
1916—Pearl Harbor dry dock. Am Soc Civil Eng Trans v 80, p 223-94, discussion p 295-337.

Staniford, Chas. W.
1914—Modern pier construction in New York. Am Soc Civil Eng Trans v 77, p 503-63.

Stearns, R. E. C.
1886—The teredo, or shipworm. Am Naturalist v 20, p 131-6.

Sterling, E. A.
1912—Development and status of the wood preserving industry in America. 8th Inter Congress Appl Chem Orig Com appendix v 26, p 17-30.
1915—Report of committee on specifications for the purchase and preservation of treatable timber. Am Woodpreservers Assoc Pro v 11, p 252-68, v 12, p 171-87, Chem Abstr v 9, p 960.
1916—Preservative treatment of farm timbers. Chicago. 16 p Nat Lum Mfg Assoc Tr Extension Dept, Farm Bul no 3.

Stevenson, David.
1862—Notice on the ravages of the limnoria terebrans on creosoted timber. J Frank Inst v 84, p 188-91.
1862—Ravages of the limnoria terebrans on creosoted timber. Civil Eng & Arch J v 25, p 205-7.
1863—Des ravages que l'insecte connu sous le nom de limnoria terebrans exerce dans les travaux à la mer sur les bois injectés de créosote. Soc de l'Encouragement Bul v 62, p 235-9, from Roy Soc Edinburgh.
1872—Notice on the ravages of the limnoria terebrans on greenheart timber. Roy Soc Edinburgh Pro v 8, p 182-5.

Stevenson, Thomas.
1874—Design and the construction of harbors. Destruction of timber by marine insects, p 175-6.

Stimson.
1917—Report of Committee on wood preservation. Am Ry Eng Assoc Bul v 18, p 1261-98.

Strength of treated timber.
1910—Report of the Committee on wood preservation of the Am Ry Eng and Maintenance of way Assoc Bul no 120, p 330-9, Eng News v 63, p 333-4, Chem Abstr v 4, p 1668.

Strength tests of structural timbers 1915 treated by commercial wood preserving processes. U S Dept of Agri Bul no 286.

Summer, and others.
1914—Report on the physical conditions of San Francisco Bay. Based on operations of U S Fisheries Steamer "Albatross," 1912-3. California U Pub Zool vol 14, no 1, 198 p.

Taft, H. S.
1915—Use of wood and concrete in structures standing in sea water. Int Eng Congress Trans Materials of eng vol p 321-61, discussion p 361-4, Chem Abstr v 9, p 3346.

Taylor, C. M.
1910—Treating timber with crude petroleum. Chem Eng v 11, p 35-6, Chem Abstr v 4, p 1667.

1915—Final inspection of timber. Am Woodpreservers Assoc Pro v 11, p 123-9.

Teesdale, C. H.
1912—Absorption of creosote by cell walls of wood. U S Dept Agr Forest Service Cir no 200, Chem Abstr v 6, p 3322.

1912—Volatilization of various fractions of creosote after their injection into wood. U S Dept Agr Forest Service Cir no 188, Chem Abstr v 6, p 1513.

1913—Condition of experimental telegraph poles, treated and untreated after eight years' service. Eng News v 70, p 1084-6.

1914—Effect of varying the preliminary air pressure in treating ties upon absorption and penetration of creosote. Am Woodpreservers Assoc Pro v 10, p 323, Chem Abstr v 8, p 2933.

1914—Efficiency of various parts of coal-tar-creosotes against marine wood borers. Eng Rec v 70, p 302-3.

1914—Penetrance of creosote. Eng Rec v 70, p 506.

1914—Penetration of timber by preservatives. Am Woodpreservers Assoc Bul v 1, p 18-9, Chem Abstr v 8, p 2934, 3623.

1914—Relative resistance of various conifers to injection with creosote. Forest Service Bul no 101.

1915—Saving creosote oil in the treatment of piling. Woodpreserving v 2, p 63, Chem Abstr v 10, p 520.

1916—Destruction of creosoted longleaf pine piling by marine wood borers. Forest Products Laboratory manuscript rept.

1916—Protection of piling from marine borers. Gulf Coast experiments, fifth inspection report. Forest Products Laboratory manuscript rept, project L-120.

1916—Treatment of wood paving blocks. Am Soc Munic Impr Pro v 23, p 79-94, Chem Abstr v 10, p 2793.

1916-7—Use of fluorides in wood preservation. Wood-preserving v 3, p 80-1, v 4, p 6-10, Chem Abstr v 11, p 1535.

Teesdale, C. H., and **McLean,** J. D.
1918—Relative resistance of various hardwoods to injection with creosote. Forest Service Bul no 606, Chem Abstr v 12, p 1592.

1918—Tests of the absorption and penetration of coal tar and creosote in long-leaf pine. Forest Service Bul no 607, Chem Abstr v 12, p 1823.

Teesdale, C. H., and **Newlin,** J. A.
1917—Influence of the proposed treatment on the strength of paving blocks and the influence which the condition of the timber at time of test may have on strength test data. Am Woodpreservers Assoc Pro v 13, p 462-90.

Teesdale, C. H., and **Shackell,** L. F.
1917—Field tests made on oil treatment of wood against marine borers. Eng News Rec v 79, p 833-7, Ry Age Gaz v 63, p 800-4.

Teichman, W. C.
1908—Railway cross-ties; experiments for their preservation by sterilization. U S Daily Consular rept no 3159, p 6.

Tennant, J.
1842—Ravages of teredo navalis prevented by studding with nails. Inst Civil Eng Pro v 2, p 169.

Tentative specifications for creosote oil 1917 for priming coat with coal tar pitch for use in damp-proofing and waterproofing. Am Soc Test Mat Pro v 17, pt 1, p 721-2, Chem Abstr v 12, p 1114.

Tentative specifications for selected 1917 structural Douglas fir bridge and trestle timbers. Am Soc Test Mat Pro v 17, pt 1, p 704-7, Chem Abstr v 12, p 1114.

Tentative specifications for Southern 1917 yellow pine timber to be creosoted. Am Soc Test Mat Pro v 17, pt 1, p 708-9, Chem Abstr v 12, p 1114.

Tentative specifications for Southern 1917 yellow pine poles and piles to be creosoted. Am Soc Test Mat Pro v 17, pt 1, p 710-11, Chem Abstr v 12, p 1114.

Tentative methods for the analysis of 1917 creosote oil. Am Soc Test Mat Pro v 17, pt 1, p 826-8, Chem Abstr, v 12, p 1114.

Teredo-proof paint and timber preserva- 1907 tive. Ry Age v 44, p 559, Ry & Eng Rev v 47, p 980.

Teredo proof sheathing for piles.
1894—Eng News v 31, p 111-12.

Thompson, W.
1847—Note on the teredo norvegica, xylophaga dorsalis, limnoria terebrans and chelura terebrans combined in destroying the submerged woodwork at the harbour of Ardrossna on the coast of Ayrshire. Ann & Mag Nat History v 20, p 157-64.

Tidy, C. M.
1885—Creosote. Van Nostrand's Eng Mag v 33, p 499-503.

Tie and lumber preserving plant at 1897 Somerville, Texas. Ry Rev v 37, p 524-5.

Tie preservation, Progress in.
1902—Ry & Eng Rev v 42, p 506.

Tie preservation in Germany.
1900—Ry & Eng Rev v 40, p 436-7.

Tie preservation in the Southwest.
1898—Ry & Eng Rev v 38, p 500.

Tie preserving.
1897—Ry Rev v 37, p 577.

Tie preserving plant, B and M Ry.
1900—Ry & Eng Rev v 40, p 172-3.

Tiemann, H. D.
1910—Physical structure of wood in relation to its penetrability by preservative fluids. Am Ry Eng & Maintenance Way Assoc Bul no 120, p 359-75.

Ties. Abstracts of report presented at 1906 the Annual meeting of the Am Eng & Main of Way Assoc Chicago. Ry Age v 41, p 464-72.

Ties—discussed by members of the com-1901-2 mittee of the Am Ry Eng & Main of Way Assoc. Ry Age v 31, p 341-48, v 33, p 439-49.

Tillson, George W.
1907—Requirements for treating wood paving blocks. Munic Eng v 33, p 319-24.

Timber perforating patent released.
1919—Ry Age v 67, p 1203-4, Ry Maintenance Eng v 16, p 17-8.

Timber-preserving methods and appli-1895 ances. Ry Eng v 16, p 181-5.

Timber preserving plant of the Alamo-1902 gordo Lumber Co. Eng News v 48, p 366-8.

Timber protection on the Santa Fe.
1917—Ry Maintenance Eng v 13, p 5-11, Chem Abstr v 11, p 1029.

Townsend, T. G.
1915—Attack of marine borers on creosoted material. Am Wood-preservers Assoc Pro v 11, p 307-16.

Tratman, E. E. R.
1894—Report on the use of metal railroad ties and on preservative processes and metal-tie plates for wooden ties. U S Dept Agr Bul no 9.

Treated ties on the Sante Fe Railroad.
1906—Ry Age v 41, p 797.

Treating lumber to prevent stain.
1907—So Lumberman v 53, no 631, p 20.

Treating railroad ties and timber.
1900—Loc Eng v 13, p 185.

Treating three million feet of lumber on 1920 the job. Eng News-Rec v 84, p 754.

Treating wood paving blocks.
1907—Munic J & Eng v 23, p 515-6.

Treatment designed to add to the dura-1903 bility of posts. R I Agr Exp Sta 16th Ann rept pt 2, p 226-9.

Treatment of mine timbers.
1921—Min Sci Press v 122, p 336.

Treatment of railway ties in England.
1889—Forest Service Bul no 3, p 49-51.

Troschel.
1912—Holzzerstörer unter wasser. Zentralblatt d Bauverwalt v 32, p 394-5, Chem Abstr v 7, p 4058.
1913—Ist die imprägnierung der wasserbauhölzer wirtschaftlich? Glasers Ann v 72, p 30-3.
1916—Handbuch der holzkonservierung. Berlin, Springer, Berlin.

U. S. Department of Agriculture, Forest 1904 Service. Timber preservation and timber testing at the Louisiana Purchase Exposition 6 p.

U. S. Surgeon-General's Office.
1872—Report on the preservation of wood, by Gen. J. K. Barnes, Gen. A. A. Humphreys, Gen. M. C. Meigs and Gen. O. E. Babcock.

Unusual record for creosoted piles.
1919—Ry Maintenance Eng v 15, p 278-80.

Use of coal tar in creosote.
1915—Report of committee on wood preservation. Am Ry Eng Assoc Pro v 16, p 825-7, Chem Abstr v 10, p 107.

Value of tie preservation.
1908—Railroad Gaz v 44, p 44.

Van der Hoeven.
1860—Observations on the teredo. Brit Assoc Adv Sci rept 30, pt 2, p 136.

Van Vloten, H. K.
1915—Resinates for preserving wood and textiles. Chem Abstr v 10, p 123, from Chem Weekblad.

Vedel, P.
1907—Destructive work of marine borers and some preventive measures against their attacks. Den Tekniske Roren Tidsskrift July 24. Trans by M. C. Jensen, Forest Products Laboratory Manuscript rept.

Verrill, G. E.
1909—Durability of creosoted lumber in sea water. Prof Mem Eng Corps U S Army, v 1, p 219-21.

Verslagen en mededeelingen der konink-1860-9 lijke akademie van wetenschappen, Amsterdam. Verslagen over den pallworm. 2, Verslag 1861, v 12, p 133-50; 3, Verslag, 1862, v 13, p 318-29; 4, Verslag 1863, v 15, p 293-310; 5, Verslag 1865, v 17, p 74-111; 6, Verslag 1866, v 1, p 157-80; 7, Verslag 1869, v 3, p 207-30.

Villon.
1894—Preservation of wood; Eng Rec v 29, p 349-50, from Revue Technique.

Vinot, G.
1897—Note sur la conservation des traverses en bois; Rev Tech v 18, p 205-7.

Vinsonneau.
1901—Du control de l'injection et de la reception des bois injectés. Rev Tech v 32, p 448-50.

Vohl.
1858—Conservation des bois, au moyen de la créosote extraite de l'huile de goudron de houille. Soc de l'Encouragement Bul v 57, p 450-1.

von Schrenk, Hermann.
1901—Decay of ties and bridge timber. Ry Age v 31, p 206.
1901—Factors which cause the decay of wood. W Soc Eng J v 6, p 89-103.
1902—Decay of timber and methods of preventing it. 96 pp. U S Plant Industry Bureau Bul 14.
1902—Report on the condition of treated timbers laid in Texas. Forestry Bul no 51.
1902—Texas experiment with treated ties. Ry & Eng Rev v 42, p 658-9.
1902—Timber preservation. W Ry Club Pro v 15, p 138-78.
1903—Chemical treatment of timber. Ry & Eng Rev v 43, p 435-6.
1903—Cutting and laying of ties. Railroad Gaz v 35, p 526.
1903—Fungous diseases of forest trees. Int Ry Congr Bul v 17, p 914-27.
1903—Recent progress in timber preservation. Year Book of Dept Agr p 427-40.
1904—Cross-tie forms and rail fastenings with special reference to treated timbers. 70 p U. S. Forestry Bur Bul 50.
1904—Recent investigation with treated ties. Eng Rec v 49, p 381-2.
1904—Some problems in the use of timber by railroads. Worcester Poly Inst J, v 7, p 315-21.
1905—Experiments with treated cross ties in Texas. Eng Rec v 51, p 440-2.
1905—Results in the preservative treatment of railroad timbers to preserve durability. Am Forest Congr Pro 1905, p 276-89.
1908—Some phases of the modern use of lumber. Southern Lumberman v 54, no 646, p 52-4.
1913—Requirements for successful timber treatment. Am Woodpreservers Assoc Pro v 9, p 142-9.
1915—Oil specification for creosoted wood block. Am Soc Munic Impr Pro 1915 Convention p 178-209, Chem Abstr v 10, p 1419.
1916—Causes of failure in creosoted wood-block pavement. Eng News v 75, p 204-6; Chem Abstr v 10, p 2289.
1916—Sampling and analysis of creosoted oil. Am Soc Test Mat Pro v 16, pt 1, p 564-71, Chem Abstr v 11, p 395.
1916—Specifications for selected structural Douglas fir bridge and trestle timber. Am Soc Test Mat Pro v 16, pt 1, p 479-82, Chem Abstr v 11, p 396.
1916—Tentative specifications for southern yellow-pine piles and poles to be creosoted. Am Soc Test Mat Pro v 16, pt 1, p 485-6, Chem Abstr v 11, p 396.
1916—Tentative specifications for southern yellow-pine timber to be creosoted. Am Soc Test Mat Pro v 16, pt 1, p 483-4, Chem Abstr v 11, p 396.
1917—Teredo destroys improperly treated piles. Ry Age Gaz v 63, p 657-8.
1918—Creosoting industry and its fire hazards. Nat Fire Prot Assoc 1918, p 399-413, Chem Abstr v 12, p 2422.
1918—Preservation of wood in connection with the building of wharves and docks. Inter Marine Eng v 23, p 230-2.
1922—Destructive action of marine borer. Canadian Eng v 43, p 390-2.

von Schrenk, Fulks and Kammerer.
1908—Changes which take place in coal-tar creosote during exposure. Am Ry Eng Assoc Pro v 9, p 738-64.

von Schrenk and Hill.
1903—Seasoning of timber. U S Forestry Bur Bul 41.

von Schrenk and Kammerer.
1914—Use of refined coal-tar in the creosoting industry. Am Woodpreservers Assoc Pro v 10, p 99-158, Chem Abstr v 8, p 2934.
1915—Specification for a coal tar creosote solution. Am Woodpreservers Assoc Pro v 11, p 152-7, Chem Abstr v 9, p 703, 1236, Eng Rec v 71, p 144.

Voorloopig verslag der Limnoria-Commissie. Verslagen en meded. Konink Akad Wetenschapen Amsterdam ser 3, v 3, p 134-40, 1886, ser 3, v 5, p 253.
1887-9

Vulcanizing process of preserving timber. Railroad Gaz v 27, p 666-7.
1895

Waddell, K. M.
1919—Proper grade of creosote oil for wood paving blocks. Munic & County Eng v 57, p 269-70.

Wade, C.
1907—Creosoted wooden poles. Timber Tr J v 62, p 570-2.

Wallis-Tayler, A. J.
1914—Preservation of wood. Roy Soc Arts J v 62, p 286-315, Chem Abstr v 8, p 1655.
1915—Preservation of wood. A descriptive treatise on the processes and on the mechanical appliances used for the preservation of wood. London, Rider.

Walsh, A. C.
1915-6—Protection from the teredo. Inst Civil Eng Pro v 201, p 125-6.

Walsh, George Ethelbert.
1902—Protecting timber from natural enemies. Arch & Bld Mag Jan, v 34, p 145-7.

Wanier, A. G.
1900—Wood preserving in Germany. Railroad Gaz v 32, p 81-2.

Ward, Marshall.
1888—Timber, its diseases. Sci Am S v 25, p 10172-3.

Water in creosote.
1915—Report of committee on wood preservation. Am Ry Eng Assoc Pro v 16, p 827-32, Chem Abstr v 10, p 107.

Water sampling in creosote oil.
1916—Report of committee on wood preservation. Am Ry Eng Assoc Pro v 17, Bul 184, p 447-58, Chem Abstr v 10, p 1088.

Water solubility a necessary property of wood preservatives. Sci Am v 124, p 431, Eng News v 85, p 940.
1920

Waterman, J. H.
1915—Treatment of red oak ties. Am Woodpreservers Assoc Pro v 11, p 110-22, Chem Abstr v 9, p 2139.
1915—Additional facts on treated ties. Am Woodpreservers Assoc Pro v 11, p 207-14, Chem Abstr v 9, p 2139.

Watkins, S. S.
1920—Effect of preliminary steaming in the treatment of air-seasoned ties. Am Woodpreservers Assoc Pro v 16, p 255-61, Chem Abstr v 14, p 1024.

Webb, E. B.
1859-60—Efficiency of copper sheathing for piles in Brazil. Inst Civil Eng Pro v 19, p 244-5.
1862-3—Action of marine worm on native timber, Bay of Rio de Janeiro. Inst Civil Eng Pro v 22, p 413.

Wehmer, C.
1913—Versuche über die hemmende wirkung von giften auf mikroorganismen. IV. Wirkung von fluorverbindungen auf hausschwamm, schimmelbildung, u. s. w. Chem Zeit v 38, p 114-5, 122-3, Chem Abstr v 8, p 1808.

Weihe, Edward J.
1907—Maximum length of service for poles, ties and timbers. St Ry J v 30, p 668-70.

Weiss, Howard F.
1907—Preservative treatment of fence posts. Forest Ser Cir 117.
1908—Open tank method of preserving timber. Elec Ry J v 32, p 1194-5, Eng News v 60, p 457-8, Eng & Min J v 87, p 840-1.
1908—Progress in chestnut pole preservation. Forest Service Cir no 147. Am Tel J v 18, p 204-7.
1912—Prolonging the useful life of cross-ties. Forest Service Bul no 118, Eng Rec v 66, p 599-600, Chem Abstr v 7, p 545.
1912—Structure of commercial woods in relation to the injection of preservatives. Am Woodpreservers Assoc Pro v 8, p 158-87.
1912—Tests to determine the commercial value of wood preservatives. 8th Int Congress Appl Chem v 13, p 279-300, discussion v 27, p 118-95, J Ind & Chem v 5, p 372-8, Chem Abstr v 6, p 3174.
1914—Teredo proof wood? Eng News v 71, p 314-15.
1916—Preservation of structural timber. McGraw-Hill, N. Y.
1917—Wooden ships and ship worms. Sci Am v 116, p 592-601.

Weiss, Howard F., and **Teesdale**, C. H.
1915—Records on the life of treated timbers in the U. S. Tables. Am Woodpreservers Assoc Pro v 11, p 501-9.
1915—Preservative treatment of timber. Inter Eng Congress Trans Materials of Eng vol p 116-59, Chem Abstr v 9, p 2807.
1915—Tests of wood preservatives. Dept of Agri Bul no 145, Chem Abstr v 9, p 1986.

Weiss, Howard F., and **Winslow**, Carlile P.
1912—Service tests of ties. Forest Service Cir no 209, 25 p.

Weiss, J. M.
1910—Antiseptic effect of creosote oil and other oils used for preserving timber. Soc Chem Ind J v 30, p 1348-53, Chem Abstr v 6, p 683.
1911—Action of oils and tars in preventing mold growth. Soc Chem Ind J v 30, p 190-1; Chem Abstr v 5, p 2327.

Weitere mitteilungen über die "limnoria
1887 lignorum" an der nordseekuste. Centralblatt der Bauverwalt v 7. p 78.

Wellington, A. M.
1880—Tests of transverse strength and resistance to spike of various woods. Railroad Gaz v 12, p 668-9.

West Pascagoula creosoting works.
1903—Ry & Eng Rev v 43, p 186-8.

Wheaton, W. R.
1912—Preservation of power transmission poles. Am Woodpreservers Assoc Pro v 8, p 225-30, Eng News v 67, p 624-5.

Whinery, S.
1904—Railroad cross-tie problem. Railroad Gaz v 37, p 526-8, 536-8.
1911—Specifications for wood block paving. Eng News v 65, p 501-2, Chem Abstr v 5, p 3508.

Widerstandsfähigkeit von grünholz ge-
1887 gen die angriffe des pfahlwurms. Zentralblatt der Bauverwalt v 7, p 204, 279.

Wilcox.
1828—Destructive action of the teredo navalis on vessels built of teak timber. Edinburgh J of Sci v 8, p 151-2.

Willert, B.
1916—Kurzer ueberblick über den stand der grubenholzimprägnierung. Kunststoffe v 6, p 197-200, Chem Abstr v 11, p 11, p 1283.

Williams, J. C.
1900—Wood preserving. Lumber Tr J v 37, no 4, p 26.
1908—Wood creosoting practice. Ry Age v 45, p 570.
1916—Wood preserving plant at Maurer, N. J. Wood-preserving v 3, p 77-9, Chem Abstr v 11, p 199.

Williams, N.
1919—Preservation of mine timber. Manchester Geol & Min Sic Trans v 36, p 79-87, Inst Min Eng Trans v 57, p 125-33, discussion p 133-5, Coll Guard v 117, p 1145-6.

Willis, Clarence P.
1910—Preservative treatment of farm timbers. U S Farmers Bul 387.

Winslow, C. P.
1908—Economic aspect of wood preservation for structural purposes. Eng Mag v 35, p 700-8.
1910—Preservation of structural timbers from decay. West Pa Eng Soc Pro v 26, p 427-53, discussion p 453-85.
1910—Results of life tests on treated and untreated chestnut poles. Forest Service Circ 198, Elect W v 60, p 1148-9, Chem Abstr v 7, p 407.
1912—Commercial creosotes for wood preservation. Forest Service Circ 206, Eng Rec v 66, p 190-2, Chem Abstr v 6, p 2834.

Winslow, C. P., and **Teesdale,** C. H.
1915—Some factors affecting the application of wood preservation to electric railways. Am Elec Ry Eng Assoc 1915, p 539-53.

Wolff, Friedenau Th.
1915—Methods for preserving wood. Kunststoffe, v 5, p 86-7, 98-100, 111-2, Chem Abstr v 9, p 1986.

Wonderful wood vulcanizing invention,
1907 A. N. Y. Lumber Tr J v 43, no 513, p 12-13.

Wood borers take the count; protecting
1921 piling by cement gun. Sci Am v 124, p 111.

Wood creosote for the preservation of
1886 timber. Eng News v 15, p 39.

Wood, Galen.
1920—Iodine-potassium ferricyanide starch color reaction test for determining zinc chloride penetration. Am Woodpreservers Assoc Pro v 16, p 182-6, Chem Abstr v 14, p 1024.

Wood piles coated with concrete applied
1920 by cement gun. Eng News v 84, p 225-6.

Wood preservation.
1903—Arboriculture v 2, p 152.

Wood preservation.
1909—Chem Abstr v 4, p 1098, from Chem Tr J.

Wood preservation.
1911—Elec Ry J v 37, p 498, Chem Abstr v 5, p 2427.

Wood preservers' association.
1908—Eng Rec v 57, p 143.

Wood preserving notes by Forest Prod-
1920 ucts Laboratory. Pub Works v 49, p 534.

Wood, To prolong life of.
1903—For & Irrig v 9, p 330.

Wood vulcanizing; a new method for
1908 seasoning and preserving gum, punky pine, etc. Packages v 11, no 4, p 64.

Woodiline for timber preservation.
1896—Engineer v 81, p 543.

Woolson, Ira H.
1902—New method of testing fire-resisting qualities of fireproofed wood. School of Mines Q v 23, p 248-62.

Yung, E.
1879—De l'action des principaux poisons sur les crustaces. Comptes Rendus, v 89, p 183-4.

Zikes, H.
1903—Ueber hausschwaum, merulius lacrymans und andere holzzerstörende pilze. Zeit Oest Ing u Arch Ver v 55, p 145.

Zinc chloride loss from treated ties.
1920—Eng News-Rec v 85, p 843.

Zinc-tannin process of tie preservation.
1891—Eng News v 26, p 95.

CEMENT AND CONCRETE IN SEA WATER

Abell, T. B.
1920-1—Reinforced concrete for ship construction. Inst Civil Eng Pro v 211, p 225-58, discussion p 259-303.

Aberthaw tests of concrete in sea water.
1921 Booklet by Aberthaw Construction Company, Boston. Gives details of tests of reinforced concrete piles which were placed in sea water at the Charlestown Navy Yard in 1909. Abstracts and comments, Eng News-Rec v 86, p 121-3, Eng & Contr v 55, p 88, 292.

Abramoff, N. M.
1908—Application du béton armé aux travaux maritimes. St. Petersbourg. Permanent International Association of Navigation Congress. Eleventh Congress, St. Petersbourg, Section II Ocean Navigation Communication 3.

Abrams, Duff A.
1923—Stone screenings as fine aggregate for concrete. Paper read before National Crushed Stone Association. Canadian Eng v 44, p 577-9.

Action de l'eau de mer sur les ciments;
1917 la commission pour l'étude des chaux et ciments de production espagnole. Ann des Ponts et Chaussées ser 9, v 37, p 253-4, Revista de Obras Publ v 65, p 101-3.

Action of alkali and sea water on con-
1913 crete; U. S. Bureau of Standards report. Eng News v 70, p 50-1.

Action of salt water on brickwork.
1920 Ferro-Concrete v 11, p 217.

Action of sea water on concrete. Con-
1907 crete Eng v 2, 139-41.

Aiken, R.
1877-8—Mazagon pier (Bombay) of liquid concrete constructed without a cofferdam. Inst Civil Eng Pro v 51, p 154-5.

Aiken, W. A.
1904—Tests of cement. Am Soc Civil Eng Trans v 54, pt F, p 37-42, discussion p 43-54.

Aki, K. and **Okabe,** S.
1923—Concrete and reinforced concrete, application to hydraulic works. Report to 13th International Congress of Navigation, London, Concrete. Second section Ocean Navigation, first communication.

Alexandre, Paul.
1888—Expériences concernant l'influence du dosage de l'eau sur la résistance des mortiers de ciment. Ann des Ponts et Chaussées ser 6, v 15, p 375-81.
1890—Recherches expérimentales sur les mortiers hydrauliques. Ann des Ponts et Chaussées ser 6, v 20, p 277-428.

Allan, Percy.
1920-1—Port improvement at Newcastle, New South Wales. Inst Civil Eng Pro v 212, p 1-34, discussion p 35-63.

Allen, Kenneth.
1921—Use of reinforced concrete in or near sea water. Munic Eng J v 7 p 66-84.

Ancient hydraulic cements. Cement & 1906 Eng News v 18, p 87.

Anderson, G. G.
1908-9—Effect of alkali on concrete. Inst Civil Eng Pro v 175, p 371-2.
1910—Effect of alkali on concrete. Am Soc Civil Eng Trans v 67, p 572-86, discussion p 587-620.

Andrews, C.
1871-2—Pozzuolana mortar. Inst Civil Eng Pro v 33, p 360.

Asch, W. and D.
1914—New investigation of the sea water question. "The silicates in chemistry and commerce." Constable, London. p 195-9.

Atlantic City steel pier in reinforced 1906 concrete, Reconstruction of. Eng News v 56, p 90-2.

Atwood, Wm. G. and **Johnson**, A. A.
1923—Disintegration of cement in sea water. Am Soc Civil Eng Pro v 49, p 1038-64.

Bache, A. D.
1835—Hardening of lime under water. J Frank Inst ser 2. v 15, p 6-8.

Baffrey, R.
1911—Use of reinforced concrete in sea water. Nat Assoc Cement Users Pro v 7, p 383-400.

Bakenhus, R. E.
1917—Tests of concrete specimens in sea water. Am Soc Civil Eng. Trans v 81, p 645-75, discussion p 676-708.

Baltimore and Ohio opens new coal pier 1917 at Baltimore. Eng Rec, v 75, p 421-2.

Bamber, H. K. G.
1909-10—Action of sea water on portland cement. Inst Civil Eng Pro, v 180, p 182-3.
1910-11—Portland cement and the question of its aeration. Inst Civil Eng Pro v 183, p 85-109, discussion p 110-217.

Barker, Ralph
1910—Application of concrete to timber structures in sea water. Nat Assoc Cement Users Pro v 6, p 158-67. Eng Rec v 61, p 363-5, cement v 10, p 397-401.

Barnes, T. Howard.
1910—Reinforced concrete wharf of the United Fruit Company at Bocas del Toro, Panama. Am Soc Civil Eng Trans v 66 p 287-302, discussion p 303-5.

Barnett, M. R.
1906-7—Effect of water on portland cement. Inst Civil Eng Pro v 167, p 180.

Barr, G. M.
1894-5—Otage upper harbour improvement works. Inst Civil Eng Pro v 121, p 200-7.

Barreau
1882—Qualités et essais des ciments à prise lente, dits portland. Ann des Ponts et Chaussées ser 6, v 4, p 150-225.

Barry.
1891-2—Failure of the lias lime mortar at Sunderland. Inst Civil Eng Pro v 105, p 125-7.

Bartholemew, Tracy.
1910—Destruction of concrete by sea and alkali water. Mining Science v 62, p 206-7.

Bateman, J. F.
1848—Sea walls: materials for submarine construction. Inst Civil Eng Pro v 7, p 198-9.

Bates, P. H.
1912—Review of the present status of iron ore cement. Nat Assoc Cement Users Pro v 8, p 566-577.
1918—Properties of portland cement having a high magnesia content. U S Bur Stand tech paper 102.
1921—Cementing qualities of the calcium aluminates. U S Bur Stand tech paper 197.
1922—Application of the fundamental knowledge of portland cement to its manufacture and use. J Frank Inst v 193, p 289-309.

Bates, P. H., **Phillips**, A.J. and **Wig**, R. J.
1912—Action of the salts in alkali water and sea water on cements. U S Bur Stand tech paper 12; Abstr Eng News v 70, p 50-1; Eng & Contr v 37, p 460-1.

Bauchere.
1906—Test of decomposition of cements by sulphates of sea water. Int Assoc Test Mat Pro Brussels, Abstract B5e. Abstr Cement Age v 1, p 336-7.

Bauxite and its uses. J Frank Inst v 156, 1903 p 317.

Bauxite: occurrence, mining, and uses. 1922 Eng & Min J-Press v 114, p 805-9.

Beavan, M.
1826—Composition d'un nouveau stuc pour les bâtimens et pour autres usages. Soc de l'Encouragement Bul v 25, p 303-4.

Beck, R.
1896—Hardening of portland cement in sea water. J Soc Chem Ind v 15, p 598; Tonind Zeit v 20, p 32-4.

Beckwith, Arthur.
1873—On the composition of ancient cements and Rosendale cements. J Frank Inst, v 95, p 204-10. Am Soc Civil Eng Trans v 2, p 171-8.

Beckwith, L. F.
1869—Action of the sea on concrete. Am Soc Civil Eng Trans v 1, p 110-11.
1869—Béton-Coignet, its fabrication and uses. Am Soc Civil Eng Trans v 1, p 93-116.

Belelubski.
1909—Action of salt water on cement. Le Ciment v 14, p 7-9; 201-4.

Belgrand.
1850—Sur l'établissement d'une conduite destinée à amener les eaux du ru d'Aillon à Avallon, suivie de quelques considérations sur les ouvrages en ciment romain. Ann des Ponts et Chaussées ser 2, v 20, p 412-51.

Bellotti, Giulio.
1910—Untersuchung eines schlackenzementes. Tonind Zeit v 34 p 64-5.

Berthault-Ducreux.
1847—De la découverte d'une pouzzolane naturelle non volcanique. Ann des Ponts et Chaussées ser 2, v 13, p 292-5.

Bétons, effets qu'ils éprouvent par l'eau
1852—de mer. Soc de l'Encouragement Bul v 51, p 864.

Bidder, G. P.
1850-1—Dock walls at Liverpool constructed of rubble. Inst Civil Eng Pro v 10, p 239-40.

Bied, J.
1902—Décomposition des mortiers par les eaux chargées de sulfate de chaux. Ann des Ponts et Chaussées ser 8, v 7, p 95-113.
1909—Experiments on the decomposition of mortars by sulphate waters. Fifth Congress Inter Assoc Test Mat Copenhagen, 1909, paper XI, discussion p 174.
1920—Ciments fondus et le four électrique. Rev de l'Ing v 27, p 191-3.
1923—Ciments à haute teneur en alumine. Soc de l'Encouragement Bul v 135, p 31-43.

Bigot, M. A.
Kaolins, argiles, beauxites, etc., perte au feu et porosité. Comptes Rendus v 174, p 1232-5.

Bishop, Carlton T.
1923—Structure of collapsed Hartford water-tank tower. Eng News-Rec v 90, p 674-5.

Bleininger, A. V.
1904—Effect of various salts on the behavior of portland cement; Erdmangers table in manufacture of hydraulic cements. Ohio Geol Sur ser 4, bul 3, p 362-5.

Blount, Bertram.
1915—Probable and presumptive life of concrete structures made from modern cements. Inter Eng Congr San Francisco, material of eng vol p 223-41.

Blyth, B. H. Jr.
1912-3—Construction of the new dock at Methil. Inst Civil Eng Pro v 191, p 76-102.

Böhme.
1885-6—Influence of the addition of various pulverized substances to cement. Inst Civil Eng Pro v 84, p 454-5.
1890-1—Experiments on pozzolana, portland and Roman cement. Inst Civil Eng Pro v 103, p 401-5.
1892—Untersuchungen von cement, kalk, kalk-trass-mörteln. Mitt Königl Tech Versuchsanstalten v 10, p 46-53.

Boisvillette.
1837—Béton: composition et métré de la maçonnerie de béton. Ann des ponts et Chaussées ser 1, v 13, p 40-9.

Bonnami.
1888—Chaux hydraulique et ciments. Soc de l'Encouragement Bul v 87, p 702.
1888—Rendement des produits hydrauliques. Ann des Ponts et Chaussées ser 6, v 16, p 99-104.

Bonnin, R.
1904-5—Lighthouses of reinforced concrete. Inst Civil Eng v 159, p 402-3.

Bougleux.
1907—Procédé de fabrication d'un ciment résistant à l'eau de mer. Moniteur de la Céramique v 38, p 170-1.

Bramah, F.
1837—Various kinds of cements. Inst Civil Eng Pro v 1, p 20.

Breuille, P.
1899—L'enduit prévu pour le mur de garde des Settons. Ann des Ponts et Chaussées ser 7, v 9, p 300-2.

Briant and **Saint Leger.**
1838—Ciment hydraulique artificiel. Soc de l'Encouragement Bul v 37, p 420.

Bömches, F.
1875-6—New harbour works at Trieste. Inst Civil Eng Pro v 46, p 288-90.

Brown, A. C.
1917—Halifax ocean terminals. Canadian Eng v 32, p 305-8.

Brown, H. E.
1912—Marine or iron ore cements. Nat Assoc Cement Users Pro v 8, p 578-96.

Brown, S. N.
1923—Setting and hardening of cements. Chem Tr J v 72, p 127-8.

Bruce, A.
1921—Action of sulphur on cement in the tropics. J Soc Chem Ind v 40, p 240 T.

Bruce, W. D.
1894-5—Kidderpur docks, Calcutta. Inst Civil Eng Pro v 121, p 88-103.

Brunlees.
1870-1—Jetties made of concrete at Fiume. Inst Civil Eng Pro v 32, p 80-1.

Buch.
1896—Versuche über die erhärtung von portland cement im meerwasser. Tonind Zeit v 20, p 32-5.

Building reinforced concrete boardwalk
1922 at Coney Island. Eng News-Rec v 89, p 229-31.

Burchartz, H.
1910—Behavior of hydraulic compounds in sea water. Engineer v 110, p 401-2; Eng Rec v 62, p 237-9; Cement & Eng News v 22, p 421-4; Eng News v 64, p 483; Chem Abstr v 5, p 183.
1910—Einfluss von chlorkalzium auf portlandzement. Mitt Königl Materialprüfungsamt v 28, p 338-43.
1913—Einfluss von trasszusatz, sowie des anmachens mit kalkwasser und seifenlösung auf die festigkeit und wasserdichtigkeit von mörtel und beton. Mitt Königl Materialprüfungsamt v 31, p 80-92, abstr J Soc Chem Ind v 32, p 658.
1915—Zement, die eigenschaften von portlandzementen, eisenportlandzementen, hochofenzementen und anderen hydraulischen bindestoffen. Königl Materialprüfungsamt v 33, p 34-72.

1915—Zement, sandfestigkeit der zemente. Königl Materialprüfungsamt v 33, p 113-26.

1917—Versuche über die einwirkung von magnesiumsulfatlösung auf zement. Mitt Königl Materialprüfungsamt v 34, p 206.

1920—Researches with blast furnace slags. Mitt Königl Materialprüfungsamt v 38, p 149-63; Chem Abstr v 16, p 998-9.

Burke, Edmund and **Pinckney,** Reuben M.
1911—Action of alkali salts upon portland cement. J Ind & Eng Chem v 3, p 317-26.

Burnell, G. R.
1856-7—Concrete blocks of natural and artificial cements used at Dover, Alderney, Cherbourg, etc. Inst Civil Eng Pro v 16, p 437-8.

1856-7—Pozzuolana mortar. Inst Civil Eng Pro v 16, p 444-5.

Butler, D. B.
1896—Effect of admixtures of Kentish ragstone, etc., upon portland cement. Soc Eng Trans p 179-86, discussion p 186-98.

Camerman, E.
1896—Influence de la nature des mortiers sur leur conservation à l'eau de mer. Ann des Travaux Pub de Belg v 1, p 123-30.

1901—Résistance des matériaux hydrauliques à la mer. Ann des Travaux Pub de Belg v 6, p 809-53.

1904—Résistance des mortiers hydrauliques à la mer. Ann des Travaux Pub de Belg v 9, p 637-58.

1905—L'étude des mortiers. Ann des Travaux Pub de Belg v 10, p 213-63.

Cameron, H. F.
1908—Concrete sea wall, Cebu, P. I. Eng Rec v 57, p 544-6, abstr Cement Age v 6, p 627.

Campbell, H. O.
1918—Concrete in marine terminals. Inter Marine Eng v 23, p 220-4.

Candlot, E.
1888—Etude pratique sur le ciment de portland. Baudry, Paris. Soc de l'Encouragement Bul ser 4, p 704, abstr Dinglers Polytech J v 273, p 471-7, 551-63, 587-600.

1889—Etude pratique sur les ciments de portland. Soc de l'Encouragement Bul v 88, p 212-29.

1890—Ciment et produits hydrauliques. Soc de l'Encouragement Bul ser 4, v 5, p 685-716.

1890—Influence of sea water on portland cement. J Soc Chem Ind v 9, p 736, abstr from Moniteur Céram et Ver v 21, p 42.

1897—Action of the sea on different kinds of mortars. Am Soc Civil Eng Trans v 37, p 523-4, abstr Eng Rec v 36, p 557-8.

1898—Ciments et chaux hydrauliques. ed 2. Baudry, Paris, 464 p.

1904—Tests of materials other than metals. Am Soc Civil Eng Trans v 54, pt F, p 31-5 and 53.

1922—La fabrication du ciment fondu. Chim & Ind p 456-7.

Carey, A. E.
1886-7—Harbor improvements at Newhaven, Sussex. Inst Civil Eng Pro v 87, p 92-108.

1896-7—Concrete in relation to marine works. Inst Civil Eng Pro v 130, p 184.

Carothers, S. C.
1923—Report to XIII International Congress of Navigation, London. Concrete. Permanent International Assoc of Nav Congresses 2nd section. Ocean Navigation, 1st communication no 56.

Carver, Geo. P.
1906—Concrete viaducts on the Key West extension of the Florida East Coast Railway. Eng Rec v 54, p 424-7; Mfg Rec v 52, October 17, 1907, p 58; Cement Age v 5, p 104-9.

Carver, W.
1923—Tests show differences between clay and concrete brick. Eng News-Rec v 90, p 1137.

Castanheira Das Neves. Die Puzzolane
1905 der Azoren. Baumaterialienkunde v 10, p 161-8.

Cathcart, W. L. and others.
1899—Dry docks. Stone vs. wood. Am Soc Civil Eng Trans v 41, p 554-95.

Cavazzi, A.
1876—Puzzuolana of St. Paul in Rome, and that of Maremma in Tuscany. Inst Civil Eng Pro v 46, p 363-5, abstr from Ing Civil e le Arti Ind v 24, p 50.

Cay, W. D.
1873-4—Construction of Aberdeen breakwater with bays of concrete. Inst Civil Eng Pro v 37, p 369-70.

1879-80—Correspondence on portland cement. Inst Civil Eng Pro v 62, p 210.

1889-90—Durability of portland cement in sea water. Inst Civil Eng Pro v 100, p 85-8.

Cement from Slag. J Frank Inst v 157,
1904 p 75.

Cement in sea water. Builder v 93,
1907 p 289.

Cement mit salzwasser. Mittheilungen
1888 über gegenstände des artillerie und gemeinwesens. p 196-7, from Scientific American.

Cement mortars, Materials for. J Frank
1837 Inst v 20, p 289.

Cement which is proof against sea wa-
1907 ter. Eng News v 58, p 645-6, Mines & Minerals v 29, p 14, Concrete Eng v 3, p 249.

Chaband-Latour.
1848—Chaux hydrauliques de Belleville. Ann des Ponts et Chaussées ser 2, v 15, p 244-59.

Chambers, Sidney H.
1910—Effect of sewage and sewage gases on portland cement. Surveyor v 37, April 29, sup p 11-12.

Chapman, C. M.
1910—Effect of sea water on the strength of cement mortars. Nat Assoc Cement Users Pro v 6, p 172-4, 291, abstr Eng Rec v 61, p 311, Concrete & Const Eng v 5, p 23-9.

Chatoney.
1857—Chaux et mortiers hydrauliques. Ann des Ponts et Chaussées ser 3, v 14, p 352-60.
1858—Mortiers de pouzzolane d'Italie. Ann des Ponts et Chaussées ser 3, v 16, p 49-50.
1858-9—Mortiers à la mer. Ann des Ponts et Chaussées ser 3, v 16, p 39-48, ser 3, v 17, p 113-4.

Chatoney and Rivot.
1856—Considérations générales sur les matériaux employés dans les constructions à la mer. Ann des Mines v 9, p 505-630, abstr in "Limes Hydraulic Cements and Mortars" by Q. A. Gillmore, 1870, p 259, chap 8.

Chenoweth, A. C.
1918—Are spirally wound concrete piles safe in sea water? Eng News-Rec v 80, p 926.

Ciment de portland gâché à l'eau de mer. 1882 Nouvelles Ann de la Constr ser 3, v 7, p 117-9.

Ciment fondu, La fabrication du. Génie 1922 Civil v 80, p 510.

Ciment résistant à l'eau de mer. Génie 1907 Civil v 51 p 420.

Ciments à haute teneur en alumine à 1923 durcissement rapide et à grande résistance: ciment fondu, ciment électrique. Génie Civil v 82, p 5-8.

Ciments fabriqués avec les scories des 1887 haut fourneaux. Ann des Ponts et Chaussées ser 6, v 14, p 285-7.

Clarke, C. E.
1885—Tests of cement made for Boston main drainage works. Am Soc Civil Eng Trans v 14, p 141-70.

Clark, E. H.
1864-65—Description of the Great Grimsby (Royal) docks. Inst Civil Eng Pro v 24, p 38-61.

Claye, L.
1888—Perméabilité des mortiers de ciment portland. Action de l'eau de mer. Ann des Ponts et Chaussées ser 6, v 15, p 816-29, abst J Soc Chem Ind v 8, p 48, Inst Civil Eng Pro v 97, p 445-7.

Cleaver, Wm.
1923—Report to 13th International Congress of Navigation, London. Concrete and reinforced concrete. Permanent Inter Assoc of Nav Congresses, 2nd section Ocean Nav. 1st communication no 56.

Coignet, Francois.
1856—Construction de digues monolithes en béton. Soc de l'Encouragement Bul v 55, p 449.
1856—Béton maigre. Ann des Ponts et Chaussées ser 3, v 12, p 41.
1859—Bétons agglomérés à base de chaux. Soc de l'Encouragement Bul v 6, p 381.

Cole, Howard J.
1909—Concrete piles. Am Soc Civil Eng Trans v 65, p 467-87, discussion p 488-513.

Collingwood, F.
1885—Behavior of cement-mortars under various contingencies of use. Am Soc Civil Eng Trans v 14, p 491-8.

Colony, R. J.
1914—Petrographic study of portland cement. Sch Mines Q v 36, p 1-21.
1921—Judging the quality of portland cement. Am Inst Min Eng Trans v 66, p 66-74, discussion p 75-81, Separate paper No 1039.

Communipaw, N. J., Freight piers at. 1911 Eng Rec v 64, p 533-4.

Composition of sea water. Data of 1920 geochemistry, U S Geol Sur Bul 695.

Concrete and reinforced concrete, Spe- 1910 cial committee on standard specifications. Am Soc Civil Eng Trans v 66, p 454-64.

Concrete covering for water main in sea 1905 water. Munic Eng v 29, p 198.

Concrete docks defy teredo. Eng Wld 1922 v 20, p 213-4.

Concrete drain tile in alkaline soil. Ce- 1922 ment & Eng News v 34, Nov 1922, p 17.

Concrete fifty years in sea water. Con- 1913 crete Cement Age v 2, p 27.

Concrete in sea water. Railroad Gaz 1887 v 19, p 570, from Engineering.

Concrete in sea water. Rept of joint 1921 committee on standard specifications for concrete and reinforced concrete. Am Soc Test Mat Pro v 21, p 239.

Concrete in the construction of salt 1921 plants. Concrete v 18, p 271.

Concrete pier at Oakland, Cal. Eng 1912 Rec v 65, p 100.

Concrete test specimens in sea water. 1911 Aberthow Construction Company tests at the Charlestown Navy Yard, Boston. Cement Age v 13, p 155-7.

Concrete work for harbors: discussion 1886-7 and correspondence. Inst Civil Eng Pro v 87, p 138-240.

Considere.
1899—Variation de volume de mortier et ciment de portland, résultant de la prise et l'état hygrométrique. Soc de l'Encouragement Bul ser 5, v 4, p 1365-9, from Comptes Rendus.

Cooper, A. S.
1899—Effect of salt water on cement. J Frank Inst v 148, p 291-302, abstr Eng News v 42, p 246.
1904—Cement from slag. J Frank Inst v 157, p 75.

Cooper, Theodore.
1902—Design of concrete piers with metal shells. Eng News v 48, p 379.

Costs of applying mortar with the ce- 1916 ment gun. Eng News v 75, p 469.

Courtois.
1834—Recherches sur les chaux, ciments et mortiers. Ann des Ponts et Chaussées, ser 1, v 7, p 45-85.
1838—Quelques recherches sur les chaux et les mortiers. Ann des Ponts et Chaussées ser 1, v 7, p 45-85. J Frank Inst v 25, p 361-83.
1838—Researches in limes and mortars. J Frank Inst v 25, p 361-83.

Craighill, W. E.
1914—Concrete where exposed to sea water or frost. Prof Mem Eng Corps U S Army v 6, p 119-23.

Crary, A. P.
1915—Some experiences with concrete in the Republic of Panama. Eng News v 73, p 214-16.

Creighton, H. J. M.
1917—Deteriorating action of salt and brine on reinforced concrete. J Frank Inst v 184, p 689-704; J Soc Chem Ind v 37, p 9-A.
1918—Reinforced concrete vs. salt brine and sea water. Chem & Met Eng v 19, p 618-23; Faraday Soc Trans v 14, p 155-163.

Crofts, C. J.
1912-3—Natal harbour works. Inst Civil Eng Pro v 193, p 32-53, discussion p 54-122.

Cross, W. M.
1912—Use of reinforced concrete in hypoclorite water purification works. Nat Assoc Cement Users Pro v 8, p 372-5.

Cummings, Uriah.
1893—American cements. Rogers & Marison, Boston.

Czarnowski, W.
1909—On the conditions of the cement blocks in some of the Russian ports in the Black and Caspian Seas. Cement in sea water. 5th Congress of the Int Assoc Test Mat Copenhagen, Paper (XI-2), discussion p 124.
1912—Preservation of test blocks immersed in the Baltic Sea at Libau harbour. Int Assoc Test Mat Pro Part 2, v 17, pamphlet 1; Abstr Eng News v 68, p 518; Eng Rec v 66, p 329.

Czarnowski, W., and **Baykoff,** A.
1906—Behavior of cement in sea water. Int Assoc Test Mat Pro 1906 Brussels, paper XI-2.

Daguenet.
1847—Ciment de Guetauy. Ann des Ponts et Chaussées ser 2, v 14, p 375.

Darcel.
1858—Mortiers et bétons de ciment. Ann des Ponts et Chaussées ser 3, v 15, p 370-3.

Dare, Henry H.
1921-2—Spillways of Burrinjuck dam. Inst Civil Eng Pro v 214, p 333-41, appendices p 342-5.

Darton, N. H.
1911—Economic geology of Richmond, Virginia and vicinity. U S Geol Sur Bul 483.

Davey, H. J.
1923—Ciment fondu. Engineering v 115, p 624.

Davis, Chandler.
1910—Concrete for marine structures. Nat Assoc Cement Users Pro v 6, p 120-57, abstr Eng & Contr v 34, p 180-4.
1917—Concrete and reinforced concrete in fresh and saline waters. Second Pan-American Sci Congr Pro v 6, p 674-88.

Deas, James.
1893—History of the conversion of the River Clyde into a navigable waterway and of the progress of Glasgow harbor from its commencement to the present day. Am Soc Civil Eng Trans v 29, p 128-68, appendices p 168-72.

De Castro, Eduardo.
1922—Los cementos para las obras en el mar. Rev de Obras Publicas, Madrid, April, 1922.

Decomposition of cement by sea water,
1901 (Presence of alumina in sea water causes formation of sulfoaluminate of lime). Eng News v 46, p 108-9.

De Joly.
1898—Résistance et élasticité des ciments portland. Ann des Ponts et Chaussées ser 7, 1898, pt 3, p 198-242.

Denison, W. T.
1866-76—Breakwater blocks of concrete at Port Said. Inst Civil Eng Pro v 26, p 445-7.

De Perrodie.
1884—Durcissement des mortiers de ciment de portland. Ann des Ponts et Chaussées ser 6, v 7, p 592-5.

Depositing concrete under water at
1898 Charlestown bridge, Boston, Mass. Eng News v 39, p 181.

De Rochemont, E. T. Q.
1891-92—Portland cements employed in the works at the Port of Havre since 1870. Inst Civil Eng Pro v 107, p 377-89.
1900—Notes sur la décomposition des ciments de portland dans l'eau de mer. Ann des Ponts et Chaussées ser 7, v 4, p 281-2, Eng News v 45, p 358.

Deryeke, R., **Goossens,** P. and **Hache,** J.
1923—Report to 13th International Congress of Navigation, London, concrete and reinforced concrete. Permanent Int Assoc of Nav Cong 2nd section Ocean Navigation 1st communication No. 2.

Desch, C. H.
1911—Chemistry and testing of cement. Edward Arnold, London, 267 pp. P 126-29 destructive action of sea water on concrete.
1918—Setting of cements and plasters. Faraday Soc Trans v 14, pt 1 p 1-45, discussion p 46-69.

Deterioration of structures of timber,
1920 metal and concrete exposed to the action of sea water. First Report of Committee of the Inst Civil Eng. Abstr Eng & Contr v 53, p 733-6, Concrete Products v 19, August p 43-4, Concrete v 17, sup p 56, Ferro-Concrete v 11, p 350-1, Chem Abstr v 14, p 2695, Nature (London) v 106, p 235-6.

Deterioration of structures in sea water.
1922—Second (Interim) Report Inst Civil Eng Pro 57 pp.

Deterioration of structures in sea water.
1923—Third (Interim) Report Inst Civil Eng Pro 79 pp.

Deval, L.
1900—Dégradation des mortiers dans les liquides salins. Soc de l'Encouragement Bul ser 5, v 6, p 669-70.
1900—Essais des ciments par filtration. Soc de l'Encouragement Bul ser 5, v 5, p 267-70.
1900—Sur la mesure des variations de volume des liants hydrauliques. Soc de l'Encouragement Bul ser 5, v 5, p 31-54.
1902—Einwirkung von kalksulfaten auf zement. Tonind Ztg v 26, p 913-15, abstr J Soc Chem Ind v 21, p 971-2, Cements, limes and plasters, by E. C. Eckel, 1909 p 602-3.

Deville, H. St. Claire.
1870—Préparation de pierres artificielles à base magnésie calcinée résistant énergiquement à l'eau de mer. Soc de l'Encouragement Bul v 69, p 393.

Different iron and slag cements.
1911—Eng News v 66, p 294.

Disintegration of cement by sea water,
1910 alkali, sewage, etc. Eng Contr v 33, p 539-40.

Disintegration of concrete and corrosion
1914 of reinforcing metal. Am Ry Eng Assoc Pro v 15, p 564-8.

Disintegration of concrete and corrosion
1921 of reinforcing material in connection with the use of concrete in sea water. Report of committee 8 on masonry. Am Ry Eng Assoc Pro v 22, p 543-5.

Dixon, J.
1886-87—Concrete breakwater at the Island of Grand Canary. Inst Civil Eng Pro v 87, p 152-3.

Dobrzynski.
1892—Einwirkung einiger chloride auf portland-cement. Tonind Ztg v 16, p 64-6.

Dock flottant en béton de 2000 tonnes du
1922 port de Trieste. Génie Civil v 80, p 489-91.

Docks and action of sea water on con-
1909 crete. Concrete Inst Trans v 2, p 5-6.

Dodwell, C. E. W.
1920—Effect of sea water on concrete structures. Canadian Eng v 39, p 279-80, Eng & Contr v 54, p 281-2, Cement & Eng News v 33, May, 1921, p 29-30, Chem Abstr v 16, p 624.

Dolot.
1888—L'action du gypse sur les mortiers. Nouvelles Ann de la Constr v 34, p 13-4.

D'Rohan, W.
1910—Effect of sea water, alkali water and sewage on portland cement. Eng & Contr v 34 p 52-4.
1916—Chemical destruction of concrete structures. Concrete v 9, sup p 11-4.

Ducorneau.
1877—Procédés d'amélioration des chaux et ciments. Soc de l'Encouragement Bul v 76, p 474-6.

Dumas.
1852-3—Chaux hydraulique. Soc de l'Encouragement Bul v 51, p 864, v 52, p 119.

Dumesnil, Adelée.
1838—Essais des mortiers. Ann des Ponts et Chaussées ser 1, v 11, p 118-28.

DuParc, M.
1829—Ciment; expériences faites à Cherbourg. Soc de l'Encouragement Bul v 28, p 328-37.

Durand and **Claye.**
1871—Classification des chaux hydrauliques. Ann des Ponts et Chaussées ser 5, v 1, p 456-66.

Durand and **Dubray.**
1886—Accidents constatés dans divers ouvrages d'art par suite de l'emploi de ciments magnésiens. Ann des Ponts et Chaussées ser 6, v 11, p 845-6.
1888—Phénomènes de dilatation des pâtes de ciment portland. Ann des Ponts et Chaussées, ser 6, v 15, p 810-5.

Durcissement, par la vapeur, des élé-
1922 ments de construction en béton, armé ou non. Génie civil v 80, p 144.

Duryee, E.
1910—Puzzolan-portland cement; a suggestion for an improved hydraulic cement. Eng News v 64, p 596-8.
1912—Further investigations of puzzolan portland cements. Eng News v 68, p 297-9.

Dyckerhoff
1895—Einwirkung von meerwasser auf hydraulische bindemittel. Zeit angew Chem 1895, p 492-4.
1897—Bericht der kommission zur ermittelung über die einwirkung von meerwasser auf hydraulische bindemittel. Deut Ver Fabr Ziegeln, usw v 33, p 58-103.
1906—Behavior of cement in sea water. Inter Assoc Test Mat Pro 1906, Brussels, p 142-60.
1910—Action of sea water on portland cement. Chem Zeit v 34, p 419; abstr J Soc Chem Ind v 29, p 567.
1910—Effect of included sulphuric acid on the strength and behavior of portland cement exposed to sea water. Eng News v 64, p 4-5, abstr. Cement Age v 11, p 118.

Dyckerhoff and **Biebrich**
1910—Über die auf sylt gemachten versuche der meerwasser kommission. Chem Zeit v 34, p 419.

Dyckerhoff and **Wideman**
1922—Festigkeit von beton. Deut Ausschuss f Eisenbeton, no 51.

Dyer, A. F.
1915—New deep water pier at Halifax, Nova Scotia. Concrete Cement Age v 7, p 7-13.
1918—Reinforced concrete in harbor works. Canadian Eng v 35, p 277-84, 289.

Eckel, E. C.
1909—Cements, limes and plasters. Wiley, N. Y.
1911—Ferrite cement and ferro-portlands. Eng News v 66, p 157-8.
1921—Quick hardening cement developed by the French. Eng News-Rec v 87, p 566-7.

1922—Cements, limes and plasters. ed 2. Wiley, N. Y.

Effect of alkali soils and water on con-
1908 crete. Munic Eng v 35, p 317-19.

Effect of salt on concrete sidewalks.
1917 Discussion. Concrete v 11, p 186.

Effect of salt water on brick, mortar and
1916 concrete. Concrete v 8, p 149, from Annali Chimi Appl.

Effect of sea water on concrete. Rail-
1906 road Gaz v 40, p 98.

Effect of sea water on concrete. Eng
1910 News v 64, p 319, from Canal Rec.

Effect of sea water on concrete. Rept
1912 Inter Nav Congr reports no 89-100, abstr Concrete Cement Age v 1, Oct 1912, p 57.

Effect of sea water on concrete. Con-
1918 crete v 13, p 35.

Effects of acids and alkaline solutions
1914 on mortar. Eng Rec v 70, p 271.

Eger.
1897—Verhalten der hydraulischen bindemittel im seewasser. Centr der Bauverwalt v 17, p 313-6.

Einwirkung des meerwassers auf mörtel.
1897—Tonind Zeit v 21, p 128-30.

Einwirkung von meerwasser auf hy-
1893 draulische bindemittel. Zeit Ver deut Ing v 37, p 317-18.

Ellis, S. H.
1911-12—Reinforced concrete wharves and warehouses at Lower Pootung, Shanghai. Inst Civil Eng Pro v 188, p 81-96.

Endres, D.
1881—Verwendung des cementbetons zu wasserbauten, u.s.w. Zeit Ver deut Ing v 25, p 521-30.

Erdmenger
1884—Cement containing magnesia. Dinglers polytech J v 252, p 135, J Soc Chem Ind v 3, p 571.

Erie builds new type of pier at Wee-
1923 hawken, N. J. Ry Age v 74, p 852-5.

Esling, F.
1919—Setting time of cement as affected by the quality of waters. Ferro-Concrete v 11, p 101-3.

Etudes sur les pouzzolanes artificielles.
1846—Soc de l'Encouragement Bul v 45, p 466.

Examples of decomposition of concrete
1908 in sea water. Eng News v 60, p 238, 453.

Expériences sur l'altération des ciments
1900 armés par l'eau de mer. Nouvelles Ann de la Constr ser 5, v 7, p 159, 175, ser 5, v 8, p 15.

Factors causing the deterioration of
1923 concrete structures. Rept Masonry Committee. Am Ry Eng Assoc Pro v 24, p 134-42.

Faija, Henry
1881—Results of experiments with portland cement gaged with sea and fresh water. Inst Civil Eng Pro, v 67, p 349-52.

1887—Portland cement testing. Am Soc Civil Eng Trans v 17, p 218-27.

1888—Effect of sea water on portland cement. Iron v 31, p 204-6.

1893—On the manufacture and testing of portland cement. Am Soc Civil Eng Trans v 30, p 43-61 discussion p 594-610.

Fairthorne, R. F.
1869—Acid proof cement. J Frank Inst v 87, p 232.

Falk, M. S.
1904—Action of sea water on cements, p 45-51. Chapter in book on "Cements, mortars and concretes"; contains a summary of results of tests by the author.

Feburier
1852—Emploi du mortier hydraulique dans l'eau de mer. Ann des Ponts et Chaussées ser 3, v 3, p 348-69.

1852—Trass de Hollande pour la fabrication des mortiers destinés aux travaux à la mer. Ann des Ponts et Chaussées ser 3, v 3, p 369-77.

1853—Construction dans l'eau de mer. Mortiers. Ann des Ponts et Chaussées ser 3, v 5, p 222-4.

Feichtinger, G.
1870—Ueber die santorinerde. Poly Centr 36 col 1685-8.

Feret, R.
1890—Diverses expériences concernant les ciments. Ann des Ponts et Chaussées ser 6, v 19, p 313-80.

1892—Compacité des mortiers hydrauliques. Ann des Ponts et Chaussées ser 7, v 4, p 5-161.

1893—Mortar for sea works. Engineering v 56, p 130.

1896—Essais des divers sables pour mortiers. Ann des Ponts et Chaussées ser 7, v 12, p 174-200, Baumaterialienkunde v 1, p 139-40.

1898—La constitution des ciments hydrauliques d'apres Newberry. Soc de l'Encouragement Bul ser 5, v 3, p 867-70.

1901—Addition de pouzzolanes aux ciments portland dans les travaux maritimes. Ann des Ponts et Chaussées ser 8, 1901, pt 4, p 191-203.

1905—Adherence of mortars to iron. Cement Age v 2, p 175-80, from Reun des Membres Franc et Belges de l'Assoc Inte Test Mat.

1905—Effect of sea water upon concrete and mortar. Concrete Plain and Reinforced, by Taylor and Thompson, chap 18, p 400-8, Wiley, N. Y., same in editions of 1909 and 1916.

1908—Aptitude des liants hydrauliques à la décomposition par l'eau de mer. Ann des Ponts et Chaussées ser 8, v 31, p 107-20.

1909—Addition of puzzolanic matter to cement and action of sea water on concrete p 342-4; general discussion of action of sea water on p 309-18. (Concrete Plain and Reinforced by Taylor and Thompson.)

1910—Resistance of cement to sea water increased by admixtures of puzzolana. Cement & Eng News v 22, p 11-8.

1913—L'imperméabilisation des mortiers et les huiles lourdes. Ann des Ponts et Chaussées ser 9, 1913, no. 51, p 413-36.

1915—L'imperméabilisation des mortiers et l'huile anthracénique. Ann des Ponts et Chaussées ser 9, v 28, p 51-69.

1922—Essais prolongés de résistance de décomposition des principaux types de liants hydrauliques. Ann des Ponts et Chaussées 1922, pt 4, p 5-33.

1922—On the choice of materials for use as sand in hydraulic mortars. Am Ceramic Soc J, v 5, p 240-2, from Rev des Mat de Const et de Trav Publics.

Feret, Le Chatelier and others.
1901—Communications presentées devant le Congres International des Méthodes d'Essai des Matériaux de Construction. Eng News v 46, p 64.

Ferguson, L. R.
1921—Concrete roof-slab failure in seashore hotel. Eng News-Rec v 87, p 271-2, 294-5.

Ferrari, F.
1920—La miscela portland-pozzolana. Gior Chim Ind Appl v 2, p 238-44, abstr Chem, Abstr v 14, p 2693, J Soc Chem Ind v 39, p 821A.

Ferro-Concrete in marine structures.
1921—Ferro-Concrete v 13, Marine number, October, 1921, p 87-114.

Foerster.
1922—Eine kraftleitung auf stahlbewehrten betonschleudermaster in Schweden. Bauingenieur v 3, p 104-7.

Forman, J. H.
1908-9—Sea walls and breakwaters. Inst Civil Eng Proc v 175, p 290-302.

Foss, A.
1910—Ueber das verhalten des zementes in meerwasser. Chem Zeit v 34, p 419, J Soc Chem Ind v 29, p 567.

Four-year tests of the effect of sea water on concrete. Eng News v 70,
1913 p 1023.

Foy, J. W.
1883—Sur les chaux les ciments et les mortiers. Ann Industrielles v 15, Col 24-6, 51-8, 81-4, 106-11, 146-54, 173-9.

Framm, F.
1911—Die veränderung der chemischen zusammensetzung von portlandzement-beton mit verschiedenem gipsgehalt im meerwasser. Chem Zeit v 35, p 256, J Soc Chem Ind v 30, p 425.

Fraser, O.
1907—Effect of confined and compressed air on exposed sea walls. Eng News v 58, p 589-90; Chem Abstr v 2, p 579.

Fresenius.
1885—On the adulteration of portland cement. Inst Civil Eng Pro v 79, p 377-80.

1903—Nachweis von fremden Beimischungen im portlandzement. Thonind Ztg v 27, p 1139-40.

Friswell, R. J.
1887—Ransome's improvement in the manufacture of portland cement. J Frank Inst v 123, p 470-5; v 124, p 61-6.

Fuller, Wm. B., and **Thompson,** Sanford E.
1907—Laws of proportioning concrete. Am Soc Civil Eng v 59, p 67-143, discussion p 144-72.

Galveston causeway, Rebuilding of.
1922—Ry Age v 72, p 1113-16.

Gary, M.
1893—Testing of portland cement and the development of the cement industry in Germany. Am Soc Civil Eng Trans v 30, p 1-42.

1900—Verhalten hydraulischer bindemittel im seewasser nach versuchen der Königl Tech Versuchsanstalten zu Berlin im auftrage der von dem Königl Ministerium der öffentlichen Arbeiten zu Berlin berufenen kommission. Mitt Königl Tech Versuchsanstalten, Berlin, Erganzungsheft 1.

1909—Bericht über das verhalten hydraulischer bindemittel im seewasser. Mitt Königl Materialprüfungsamt v 27, p 239-317, abstr Cement Age, v 9, p 364-8, Tonind Zeit v 33, p 1232, Concrete & Const Eng v 5, p 23-9.

1915—Prüfung von eisenportlandzement bei lufterhärtung im vergleich zur wassererhärtung. Mitt Königl Materialprüfungsamt v 33, p 271-90.

1919—Bericht über das verhalten hydraulischer bindemittel im seewasser. Mitt Königl Materialprüfungsamt v 37, p 132-70; Chem Abstr v 14, p 2694.

1919—Feinde des zementes. Mitt Königl Materialprüfungsamt v 37, p 12-18 Chem Abstr v 14, p 2541.

Gary, M., and **Burchartz,** H.
1909—Prüfung von eisenportlandzement im vergleich zu portlandzement. Mitt Königl Materialprüfungsamt v 27, p 338-74.

1915—Zement-prüfung von eisenportlandzement im vergleich zu portlandzement. Mitt Königl Materialprüfungsamt v 33, p 29-34.

Gassier.
1912—Notes on the comparative mechanical strength and the stabilities in sea water of crushed sand mortars and sea sand mortars. Inter Assoc Test Mat Pro rept XVII-5, discussion section B, p 104.

Gay-Lussac.
1837—Pierre à chaux: calcination. Ann des Ponts et Chaussées ser 1, v 14, p 364-7.

German Collos Cement Co.
1911—Cement for use in salt water. German patent 225, 289, March 25, 1906; Chem Abstr v 5, p 584.

Gillmore, Q. A.
1863—Treatise on limes, cements and mortars. Van Nostrand, N. Y.

1890—Effect of salt water on mortars. Eng News v 24, p 542-3.

Gilos, A.
1857-58—On the construction of the Southampton docks. Inst Civil Eng Pro v 17, p 540-54.

Giorgis, G., and Cenni, G.
1915—Composition of portland cement mortars in sea water. Ann Chim Appl v 3, p 168-81, abstr Concrete Cement Age v 7, p 144, Chem Abstr v 9, p 1679-80.

Gobin, A.
1887—Fabrication des chaux hydrauliques dans le Bassin du Rhône. Ann des Ponts et Chaussées ser 6, v 14, p 464-5.
1889—Les ciments de l'Isère. Ann des Ponts et Chaussées ser 6, v 17, p 755-828.

Goslich-Züllchow.
1910—Bericht über die tätigkeit der Deutschen Ausschüsse für Eisenbeton und für Beton-versuche im moor. Chem Zeit v 34, p 419.
1910—Bericht über den stand der schlacken-mischfrage. Chem Zeit v 34, p 419.
1910—Über Concordia-zement. Chem Zeit v 34, p 419.
1910—Über die wirkung des schwefels im eisenportlandzement und portlandzement. Chem Zeit v 34, p 419.

Graf, Otto.
1920—Versuche zur ermittlung der widerstandsfähigkeit von betonkörpern mit und ohne trass. Deut Ausschuss für Eisenbeton no 43.

Grant, John.
1865-71—Experiments on the strength of cement chiefly in reference to the portland cement used in the Southern Main Drainage works. Inst Civil Eng Pro v 25, p 66-111, v 32, p 266-328, discussion v 25, p 112-58.

Grant, William H.
1891—Notes on cements, mortars and concretes. Am Soc Civil Eng Trans v 25, p 259-79, discussion p 279-94.

Grierson, W. W.
1922—Reinforced concrete. Inter Ry Assoc Bul v 4, p 643-52.
1922—Use of concrete on railways. Effect of sea water. Canadian Eng v 42, p 680.

Gnelle, M.
1923—Note sur l'emploi du silicate de soude comme liant. Ann des Ponts et Chaussées 1923, pt 1, p 42-6.

Hadfield, Robert.
1923—Concrete and reinforced concrete. Their application to hydraulic works; means to insure their preservation and their watertightness. Rept to 13th International Congress of Navigation, London, 64 pp.

Halifax ocean terminal work, Concreting
1915-6 plant for. Eng News v 74, p 368, v 75, p 249-53.

Hall, W. J.
1890-91—Failure of the Limerick dock walls and the methods adopted for reconstruction and repairs. Inst Civil Eng Pro v 103, p 257-63.

Hambloch, Anton.
1909—Trass, seine entstehung, gewinnung und bedeutung im dienste der technik. Zeit Ver deut Ing v 53, p 663-8.
1911—Hydratwasser im trasse. Armierter Béton v 4, p 195-7.
1913 Ein weiterer beitrag zum thema über zement-kalkmörtel bei talsperrenbauten. Armierter Beton, v 6, p 198-202.
1913-14—Exposure of reinforced-concrete structures to the action of sea water. Inst Civil Eng Pro v 197, p 532-3.
1914—Eisenbeton im meerwasser. Armierter Beton v 7, p 23-7.

Harrison, J. L.
1916—Cracking of reinforced concrete by salt water. J Soc Chem Ind v 36, p 86, Eng & Min J v 102, p 1019-20.
1916—Effect of using salt water for gaging concrete on the life of the reinforcing steel. Board of Public Works Quarterly Bul Manila, v 5 no 2, p 19-22, abstr Eng & Contr v 46, p 443-6, Eng News v 76, p 1047, Eng Club of Baltimore J v 6, p 131-6.
1917—Effect of sea water on concrete structures in the Philippines. Eng & Contr v 4, p 580-2.
1917—Effect on reinforcing steel of using salt water in concrete. Concrete v 10, p 110-12.
1917—Limestone aggregate in sea water. Concrete v 11, p 88.
1919—Concrete in sea water. Concrete v 15, p 198-200.

Hartley, C.
1865-6—Composition of mortar for the Spezzia dock walls. Inst Civil Eng Pro v 25, p 150-3.

Hasch.
1923—Das verhalten von beton und mörtel im moor. Oest Ing u Arch Ver Zeit v 75, p 120-1.

Haswell, C. H.
1865-6—Limes, cements, mortars and concretes. J Frank Inst v 79, p 361-7, v 80, p 171-5, and v 82, p 295-302.

Hauenschild.
1897—Verwendung von kalk-trassmörtel. Tonind Zeit v 21, p 431-2.

Haupt, Lewis M., and others.
1904—Shuman's c o n c r e t e piles. J Frank Inst v 160, p 455-9.

Hawkins, J. J.
1826—Roman cement. J Frank Inst v 1, p 197.

Hawkshaw, J.
1864-5—Durability of concrete blocks in sea water. Inst Civil Eng Pro v 24, p 168-9.

Hawthorn, T.
1864-5—Account of the docks and warehouses at Marseilles. Inst Civil Eng Pro v 24, p 144-67, discussion p 168-83.

Hayter, H.
1892-3—Partial failure of the concrete walls of the Alexandra dock, Belfast. Inst Civil Eng Pro v 111, p 86-8.

Heath-clay for cement in sea water.
1906-7—Inst Civil Eng Pro v 168, p 436-9.

Heidenreich, E. Lee.
1923—Ciment fondu or alcement. Lecture to the Danish Engineering Society. Concrete v 22, p 25-8.

Hell Gate Bridge, New York.
1915—Engineer v 120, p 495-7.

Herrmann.
1923—Über betonzerstörungen durch sulfate und andere schwefelhaltige stoffe. Zentr der Bauverwalt v 43, p 1-3, 15-7.
1923—Über die wirkung von trass in mischung mit portlandzement. Deutsche Bauzeitung v 57, p 38-40.

Herstellung von portlandzement aus 1903 hochofenschlacken. Zeit Ver deut Ing v 47, p 689-90.

Heyn and Bauer.
1909—Corrosion of iron in water and aqueous solutions. Fifth Inst Assoc Test Mat Pro section 17, pt 1.

Higgins, Bryan.
1780—Experiments and observations on calcareous cements. Cadell, London, 233 pp.

High alumina cement. Engineering 1922 v 114, p 180.

Hill, James M.
1921—Bauxite and aluminum in 1917. U S Geol Sur, Min Res of U S 1917, pt 1, p 1-9.
1921—Bauxite and aluminum in 1918. U S Geol Sur, Min Res of U S 1918, pt 1, p 513-25.
1923—Marketing of bauxite. Eng & Min J-Press v 115, p 800-2.

Hiroi, I.
1905—Preparation and use of concrete blocks for harbor works. Am Soc Civil Eng Trans v 54, pt A, p 211-36.
1913—On long time test of portland cement. Am Soc Civil Eng Trans v 76, p 1027-32, discussion p 1033-44.
1920—On long time tests of portland cement, hydraulic lime and volcanic ashes. J College of Eng Toyko Imp U v 10, no 7, p 155-72.

Hodgdon, F. W.
1911—Disintegration of concrete works in Boston harbor. Eng Rec v 63, p 631, 655-6.

Hollister, S. C.
1923—Behavior of concrete exposed to sea water. Am Soc Test Mat Pro v 23, pt 2, p 202-10, discussion p 211-47.

Hood, W.
1915—Use of concrete in sea water. West Eng v 6, p 182, abstr Concrete Cement Age v 7, p 205.

Horton, C. C.
1910—Efficiency and cost of concrete for the preservation of piles exposed to sea water. Nat Assoc Cement Users Pro v 6, p 169-71.

Hosbach.
1910—Temperaturerhöhung beim abbinden von portlandzement. Chem Zeit v 34, p 433.

Howell, C. S.
1916—Bottom driven concrete piles on government job. Eng News v 76, p 1207.

Huber, F. W.
1912—Concrete in sea water. Am Contr v 33, no 8, p 67.
1914—Factors controlling the durability of concrete in sea water. West Eng v 5, p 197-201.

Huck.
1870—Neues verfahren zur gewinnung eines cementes aus hochofenschlacken. Poly Centr v 36, col 778.

Hughes, J.
1888—Composition of ancient mortar. Builder v 54, p 333.

Huisman, H.
1906-7—Sea coast protection with reinforced concrete. Inst Civil Eng Pro v 169, p 443-5.

Humphreys, G. W.
1923—Concrete and reinforced concrete. Report to 13th Inter Navigation Congress, London, 21 pp.

Humphrey, R. L.
1901-2—Inspection and testing of cements. J Frank Inst v 152, p 441-61, v 153, p 23-42, 93-118.
1915—Waterproof concrete. Inter Eng Congr, San Francisco, Materials of Eng vol p 274-320.

Hutchins, H. C.
1908—Effects of chemical action on reinforced concrete. Concrete Age v 8, p 19-22, Chem Abstr v 2, p 2140.

Hyde, G. W. and **Smith**, W. J.
1889—Experiments to determine the permeability of cements and cement mortars. J Frank Inst v 128, p 199-207.

Hydraulic Cement. J. Frank Inst ser 3, 1877 v 74, p 372.

Hydraulic cement, Cause of hardening 1869 of. J Frank Inst ser 3, v 58, p 66.

Improved system of concrete piling. J 1905 Frank Inst v 160, p 455-9.

Influence of sea water on concrete. Con-1921 crete Products v 21, Aug. p 44.

Investigation of concrete structures in 1917 sea water. Public Works of the Navy bul no 27, p 10-1.

Investigation of concrete structures in 1917 sea water, Navy Yard, Boston, Mass. Public Works of the Navy bul no 27, July 1917, p 12-26.

Investigation of concrete structures in 1917 sea water, Navy Yard, Puget Sound, Wash. Public Works of the Navy bul no 27, July 1917, p 26-34.

Iron and slag cements. Eng News v 66, 1911 p 294.

Investigation of concrete structures in 1917 sea water. Public Works of the Navy bul 27 and 28.

James, E. A.
1923—Bituminous concrete and penetration surfaces. Canadian Engr v 44, p 403-4.

Jewett, J. Y.
1912-3—Alkali action on concrete. Investigation by the U. S. Reclamation Service. Eng Mag v 44, p 267-9.

Johnson, A. A. and **Atwood, W. G.**
1923—Disintegration of cement in sea water. Am Soc Civil Eng Pro v 49, pt 2, p 1038-64.

Johnson, J. B.
1892—Time tests of natural cement mortars. Railroad Gaz v 24, p 214-5.
1898—Materials of construction. Wiley & Sons, N. Y. 4th ed. 5th ed revised by M. O. Withey and J. Aston, 1919.

Johnson, N. C.
1915—Mechanical disintegration of defective concretes. Eng Rec v 71, p 160-4, Concrete Cement Age v 7, August, p 51.
1918—Old treatises emphasized same points. Eng News-Rec v 80, p 261-5.

Johnson and **Pulver.**
1913—Effect of salts upon concrete cured at low temperature. Wis Eng v 18, p 6-13, abstr Concrete-Cement Age v 3, p 265-7.

Jones, H. D.
1842—Beton used in France for the construction of sea defenses. Inst Civil Eng Pro v 2, p 126.

Julien.
1834—Pouzzolanes artificielles. Ann des Ponts et Chaussées ser 1, v 8, p 30-44.

Jünemann.
1867—Ciment durcissant et résistant aussitôt au feu et à l'eau. Soc de l'Encouragement Bul v 66, p 61, from Dinglers polytech J.

Kagenbusch.
1843—Pouzzolane fabriquée avec le schiste alumineux. Soc de l'Encouragement Bul v 42, p 483.

Kalisch.
1861—Préparation d'un ciment pour bassins et réservoirs, destiné à les rendre pas lessives alcalines bouillantes. Soc de l Encouragement Bul v 60, p 696.

Kammuller, K.
1922—Über die prüfung der wasserdurchlässigkeit von beton und mörtel. Bauingenieur v 23, p 710.

Kasai, S.
1907—Ueber ausdehnung von portlandzementmörtel in süsswasser und in meerwasser. Tonind Zeit v 31, p 248-51, abstr Cement Age v 4, p 261.

Kelley, W. R.
1892-3—Alexandra graving dock, Belfast. Inst Civil Eng Pro v 111, p 59-74. Discussions relative to the disintegration of concrete in sea water p 86-7.

Kenny, W. E.
1914-5—Screw pile and reinforced concrete lighthouses, Malacca Straits. Inst Civil Eng Pro v 199, p 196-8.

Kenyon, George Cecil.
1904—Dock improvements at Liverpool. Am Soc Civil Eng Trans v 52, p 36-64, dicussion p 65-72.

Kidd, W.
1890-1—Method of constructing the sub-aqueous part of piers and breakwaters with soft unset concrete. Inst Civil Eng Pro v 105, p 231-7.

King, A. E. W.
1916—Pozzuolanic properties of Meycauyan volcanic tuff. Philippine J Sci v 11 A, p 19-35, Chem Abstr v 10, p 2973.

Kingsbury, W. J.
1858-9—Description of the entrance, entrance lock and jetty walls of the Victoria (London) docks. Inst Civil Eng Pro v 18, p 445-76, discussion p 477-89.

Kinipple, W. R.
1886-7—Concrete work under water. Inst Civil Eng Pro v 87, p 65-75.

Klapp, Eugene.
1910—Reinforced concrete pier construction. Am Soc Civil Eng Trans v 70, p 448-54, discussion p 455.

Klaudy, J.
1909—Tests of cement mortars exposed to sea water and other salt solutions. Committee report. Oestere Ing Arch Ver Zeit v 61, p 676-80, abstr Cement Age v 10, p 40, Eng News, p 632-3.

Klein, A. A.
1922—Constitution et l'hydratation du ciment portland. Chim & Ind v 7, p 1150, from Zement.

Kloes, J. A.
1906—Trass und meerwasser. Baumaterialienkunde v 11, p 41-8.
1909—Action of sea water on concrete. Inst Civil Eng Pro v 182, p 360; De Ingenieur v 25, p 471-2.

Koning, N. M. and **Bienfort, L.**
1894-5—Test of cement and trass mortars hardening in fresh or sea water. Inst Civil Eng Pro v 120, p 376.

Krantz.
1844—Sur divers procédés employés pour la fabrication du mortier et du béton sur les chantiers du port d'Alger. Ann des Ponts et Chaussées ser 2, v 8, p 300-31.

Kuhlmann.
1856—Intervention des silicates alcalins dans la production artificielle du ciment de la chaux hydraulique, etc. Soc de l'Encouragement Bul v 55, p 106-10.

Kyle, J. C.
1886-7—Colombo harbor breakwater. Inst Civil Eng Pro v 87, p 79-91.
1896-7—Experience in laying concrete in the sea. Inst Civil Eng Pro v 130, p 183.

Landrin, Ed.
1883—De l'action de l'eau sur la chaux du Theil, et de l'existence d'un nouveau composé hydraulique, le pouzzo-portland. Rev Industrielle, 1883, p 224.

Le Blanc.
1865—Ciment de portland. Ann des Ponts et Chaussées ser 4, v 10, p 84-98.

Lebor, J. B. and **Richardson, C.**
1914—Amount of SO_3 in portland cement. Eng Rec v 70, p 144.

Lebrun.
1832—Béton, de son emploi pour les construction des édifices. Soc de l'Encouragement Bul v 31, p 99-103.

Le Châtelier, H.
1882—Recherches sur la constitution des ciments et la théorie de leur prise. Ann des Ponts et Chaussées ser 6, v 3, p 482-5.
1884—Décomposition des ciments. Soc de l'Encouragement Bul v 83, p 551-2.
1885—Mesure de la résistance des mortiers. Soc de l'Encouragement Bul v 84, p 285.
1886—Ciment de laitiers. Soc de l'Encouragement Bul v 85, p 580-9.
1887—Recherches expérimentales sur la constitution des mortiers hydrauliques. Ann des Mines ser 8, v 11, p 345-65.
1889—Rapport sur le concours pour une étude sur les propriétés des ciments. Soc de l'Encouragement Bul v 88, p 48-53.
1890—Ciment de laitier par M. Henry. Soc de l'Encouragement Bul v 89, p 26-8.
1893—Procédés d'essai des matériaux hydrauliques. Ann des Mines ser 9, v 4, p 252-419.
1895—Extinction et silotage des chaux et ciments. Soc de l'Encouragement Bul v 94, p 52-62.
1899—Mécanisme de la désagrégation des mortiers hydrauliques. Soc de l'Encouragement Bul v 98, p 485-1.
1900—Sur les changements de volume qui accompagnent le durcissement des ciments. Soc de l'Encouragement Bul v 99, p 54-7.
1901—Decomposition of cement by sea water. Eng News v 46, p 108-9.
1902—Action of sea water on cement. Cement & Eng News v 13, Oct 1902, p 57.
1902-3—Sur la perméabilité par diffusion des mortiers. Soc de l'Encouragement Bul v 102, p 89-6, abstr Inst Civil Eng Pro v 152, p 388.
1904—Décomposition des ciments. Ann des Min ser 10, v 6, p 251-331, abstr Cement Age v 1, p 415-24.
1906—Decomposition of cements in sea water. Munic Eng v 30, p 441-5, Eng Rec v 54, p 356, Eng News v 56, p 377, Am Manuf & Iron Wld v 76, p 406-8, 431-6.
1907—Observations préliminaires au sujet de la décomposition des ciments à la mer. Ann des Ponts et Chaussées ser 8, v 26, p 26-117, abstr Sci Am v 98, p 462.
1909—Decomposition of cement by sea water. 7th Int Congr Appl Chem Pro Sec 2, abstr Quarry v 14, p 27-9.

Le Duc, E.
1903—Influence of sea water on cements. Cement Age v 1, p 502-3, from Inter Assoc Test Mat, 1903.
1903-4—Action de l'eau de mer sur les mortiers. Bull du Lab d'Essais Mécaniques, Physiques, Chimiques et de Machines du Conservatoire Nat des Arts et Métiers v 1, no 3, 30 p.

Lepnik, Franz.
1923—Wasserstollenbau im druckhaften gebirge. Oesterc Ing Arch Ver v 75, p 116-8.

Lesley, R. W.
1898—History of the portland cement industry in the United States. J Frank Inst v 146, p 342-42, discussion p 342-8.

Lesley, R. W., and others.
1903—Impervious concrete. Am Soc Civil Eng Trans v 51, p 114-35.

Lidy, M.
1899—Expériences sur l'altération des ciments armés par l'eau de mer. Ann des Ponts et Chaussées ser 7, v 4, p 229-37.

Lighthouses of ferro-concrete. Inst 1903-5 Civil Eng Pro v 156, p 477-8, from Génie Civil.

Lippincott, J. B.
1913—Tufa cement as manufactured and used on the Los Angeles aqueduct. Am Soc Civil Eng Trans v 76, p 520-45, discussion p 548-81, abstr Inst Civil Eng Pro v 192, p 359-60.

Ljamin.
1909—Ueber den weissen zement von Timosejew. Tonind Zeit v 33, p 241.

Lloyd-Davis, D. E.
1915—Harbor and coast defence work at Alexandria, Egypt. Engineering v 100, p 603.
1915-8—Reinforced concrete breakwater. Inst Civil Eng Pro v 201, p 87.

Lock joint concrete pipe. Eng News 1906-8 v 55, p 20-1, v 59, p 108.

Loebell.
1901—Bestimmung des freien kalkes in cementklinker und kalkhydrates in erhärten portland-cement. Tonind Zeit v 25, p 1437-8.

Lombard and **Deforge.**
1912—Action of sea water on hydraulic binding media. Int Assoc Test Mat Pro XVII-2, 1912, abstr Eng News v 68, p 518, Eng Rec v 66, p 265.

Lossier, Henry.
1922—Béton armé et le ciment fondu. Construction des ouvrages en béton armé à grande portée. Génie Civil v 80, p 79-83.
1923—Résultats d'expériences sur les ciments à durcissement rapide. Génie Civil v 83, p 204-7.

Lothary.
1867—Cem. contra portland cement. J für Gasbeleuchtung 1867, v 10, p 520-8.

Luiggi, Luigi.
1912—Précautions pour assurer l'imperméabilité des travaux en ciment armé. Ann des Ponts et Chaussées 1912, pt 2, p 601-3, from Ann d Stad Ing e d Arch.
1919—Cenni sommari sull'impiego delle pozzolane nelle opere marittime Italiane. Gior del Genio Civile. Rev d Lav Pub v 57, p 323-6.

Luiggi and **Cardi.**
1893—Esperimenti sulle calci, sabbie, pozzolana, cementi, malte e murature, eseguiti durante i lavori del porto di Genova. Gior del Genio Civile v 31, p 445-573.

Lundahl, R. R.
1923—Bond strength of wood piles in concrete. Am Soc Civil Eng Trans v 86, p 268-79.

Lundteigen, A.
1897—Notes on portland cement concrete. Am Soc Civil Eng Trans v 37, p 501-8, discussion p 509-36.

Lynch, T. W. K.
1914—Deck water terminals at Halifax. Canadian Eng v 27, p 229-33.

Lyster, G. F.
1889-90—Liverpool docks. Inst Civil Eng Pro v 100, p 2-39.

McCrory, S. H.
1922—Effect of alkali upon concrete. Cement & Eng News v 34, no 6, p 17-8.

McKibben, F. P.
1921—Some examples of corrosion of reinforcing steel. Eng News-Rec v 87, p 509, 531-2, Chem Abstr v 16, p 325.

Mackenzie, A. C.
1917—Port of Melbourne. Construction of a new railway pier. Commonwealth Eng v 4, p 178-82.

Mackenzie, Wm. B.
1905—Destruction of concrete by alternate freezing and thawing between tide levels. Eng News v 53, p 231.
1912—Destruction of concrete between tides in sea water. Eng News v 88, p 29.
1913—Protection of concrete in sea water, between high and low tide. Pro 23d Ann Convention Am Ry Bridge & Building Assoc 1913, p 331-41.

Magnel, G.
1923—Étude expérimentale sur le béton au ciment fondu. Ann de l'Assoc des Ing sortis des Écoles spéc de Gand v 3, p 139-62.

Mahon, R. W.
1894—Slag cement experiments. J Frank Inst v 137, p 184-90.

Maier, Fr.
1922—Entstehung des porenvolumens im beton und seine beziehung zur dichtigkeit und festigkeit. Bauingenieur 1922, p 558-62.

Malaguti and **Durocher.**
1854—Résistances des chaux hydrauliques. Soc de l'Encouragement Bul v 53, p 539.
1854—Recherches sur la résistance des chaux hydrauliques et des ciments à l'action destructive de l'eau de mer. Comptes Rendus v 39, p 183-8.

Manes.
1846—Chaux et ciments hydrauliques. Ann des Ponts et Chaussées ser 2, v 11, p 116-24.

Mangeot.
1836—Chaufournerie. Ann des Ponts et Chaussées ser 1, v 12, p 147-84.

Mathews, Ernest R and **Watson,** James.
1909—Action of frost on cement and cement mortar together with other experiments on these materials. Am Soc Civil Eng Trans v 64, p 330-2, discussion p 333-51.

Matsumoto, Torata.
1921—Study of the effect of moisture content upon the expansion and contraction of plain and reinforced concrete. Illinois U Eng Expt Sta Bul 126.

Matthews, E. R.
1908—Effects of freezing and immersion on cement mortar. Cement & Eng Digest v 4, p 405-7, Surveyor v 35, p 350-2.
1909—Corrosion of steel reinforcement in concrete. Soc Eng Trans 1909, p 61-92.
1920—Flood prevention works at Troan, Ayrshire and the action of sea water on concrete. Surveyor v 57, p 329-32, abstr Eng & Contr v 53, p 739.
1920—Deterioration of structures in sea water. Concrete & Constr Eng v 15, p 392-4, Chem Abstr v 14, p 2695.

Matthews, Wm.
1907-8—First use of portland cement at the Dover Admiralty pier in 1840. Inst Civil Eng Pro v 171, p 106.

Mayer, E.
1903—Influence of sea water on hydraulic materials, particularly on cement. Inter Assoc Test Mat Pro 1903, abstr J Soc Chem Ind v 22, p 29.
1903—Tests of influence of sea water on cement at LaRochelle. Int Assoc Test Mat Pro 1903 (non-official report B 6f, 1906, French text).
1907—Action of sea water on mortars. Cement Age v 4, p 169-74.

Maynard, E.
1905—Action du chlorure de sodium sur la prise et importance de l'action sur la désagrégation des mortiers immergés en eau de mer. Rev Tech v 26, p 706.
1906—Béton armé. Tonind Zeit v 30, p 440-4, Rev Tech v 26, p 453-7, abstr J Soc Chem Ind v 25, p 985-6.
1906—On the necessity of modifying the process actually followed in analyzing cement mortars and in sampling them. Inter Assoc Test Mat non-official papers B8e.
1906—Mechanism of the deterioration of cement mortars and the rapid determination of their behavior in the sea by the manner in which they decompose. Inter Assoc Test Mat non-official papers B9c.
1909—Auflösung und zersetzung der zemente. Tonind Zeit v 33, p 1462.

Meade, R. K.
1913—Action of various substances on cement mortars. Am Soc Test Mat Pro v 13, p 813-20, discussion p 21-7, abstr Concrete Cement Age v 3, August, p 59.

Mercier.
1902—Essais comparatifs de rendement de mortiers et bétons avec ciments de laitiers et ciments portlands. Ann des Ponts et Chaussées ser 8, v 7, p 128-34.
1906—Influence de la température de l'eau dans laquelle sont conservées les éprouvettes d'essai sur leur résistance. Ann des Ponts et Chaussées ser 8, v 21, p 150-69.

Mesnager.
1913—Changements de dimensions avec le temps du béton armé ou non. Ann des Ponts et Chaussées 1913, pt 2, p 710-4.

Messent, P. J.
1886-7—Neglect of Roman cement by modern engineers. Inst Civil Eng Pro v 87, p 148-52.
1888—Concrete in sea water. Engineering v 45, p 100-1.

Mezger, R,
1922—Zerstörender angriff auf beton durch gaswasser. Bauingenieur 1922, p 408-12.

Michaelis, W., Sr.
1867—Zur mörtel-frage. F. G. Wieck's Deutsche Illustrierte Gewerbezeitung v 32, from Monatschr, d. G.-V. f. Köln, p 36.
1871—On the use of hydraulic mortar. J Frank Inst v 91, p 281-5, 332-7, 419-22, v 92, p 141-4, 196-9.
1876—Zur werthstellung der zemente. Deut Bauzeitung v 10, p 505-7.
1877—Grundsatze für die werthstellung des portlandcementes. Dinglers polytech J v 223, p 220, v 224, p 188-93, 287-92, 417-24.
1891-2—Behavior of portland cement in sea water. Inst Civil Eng Pro v 107, p 370-6.
1892—The cement bacillus. Engineering v 54, p 22-3.
1895—Résistance des matériaux hydrauliques à l'eau de mer. Pamphlet published by Dunod, Paris, 1895, p 34.
1896—Admixture of Kentish ragstone with portland cement. Engineering v 61, p 753-4.
1896-7—Action of seawater upon hydraulic cements. Inst Civil Eng Pro v 129, p 325-33.
1897—Behavior of hydraulic concrete in sea water. Published in Berlin, 1895. Abstr Am Soc Civil Eng Trans v 37, p 520-4.
1897—Résistance des ciments à l'eau de mer. Soc de l'Encouragement Bul v 96, p 819-31.
1897—Résistance des matériaux hydrauliques à le mer. Ann des Trav Pub de Belg v 2, p 237-51.
1900-1—Formula for the composition of a good cement mixture. Inst Civil Eng Pro v 145, p 116-8.
1907—Cement which is proof against sea water. Eng News v 58, p 645-6.
1909—Der erhärtungs prozess der kalkhaltigen hydraulischen bindemittel. Zeit. f. Chemie v 5, p 9-22.
1909—Puzzolanekalkmörtel im meerwasser. Tonind Zeit v 33, p 1308, Chem Abstr v 3, p 3005.
1911—Iron ore cement in sea water. Cement & Eng News v 23, p 112-3.

Miles, F. B.
1872—Brickdust cement. J Frank Inst v 93, p 15-6.

Miller, D.
1862-3—Structures in the sea without cofferdams; with a description of the works of the New Albert harbor at Greenock. Inst Eng Pro v 22, p 417-38, discussion p 439-50.

Miller, Dalton G and **McCrory,** S. H.
1921—Investigations relating to failures of concrete tile. First biennial report of commissioner of Drainage and Water, State of Minn, p 130-6.

Minard, J.
1833—Substance pouzzolanique dans l'Aisne. Ann des Ponts et Chaussées ser 1, v 6, p 269-76.
1833—Influence de la chaleur sur les mortiers hydrauliques. Ann des Ponts et Chaussées ser 1, v 5, p 325-9.
1853—Mortiers employés à la mer. Ann des Ponts et Chaussées ser 3, v 5, p 186-95.
1853—Analyses de trass par Rivot. Ann des Ponts et Chaussées ser 3, v 5, p 218-9.
1853—Constructions à le mer faites avec des pouzzolanes artificielles. Soc de l'Encouragement Bul v 52, p 125.
1854—Chaux et mortiers à la mer. Ann des Ponts et Chaussées ser 3, v 8, p 11-9.
1856—Durcissement des mortiers marins. Ann des Ponts et Chaussées ser 3, v 11, p 1-5.
1858—D'un nouveau mode d'essai des mortiers marins. Ann des Ponts et Chaussées ser 3, v 15, p 115-20.
1859—Mortier marin de pouzzolane. Ann des Ponts et Chaussées ser 3, v 17, p 236-8.

Mitchell, James.
1923—Concrete and reinforced concrete. Report to XIII Inter Congr of Navigation, London, no 56, p 19-26.

Moller, H. C. V.
1885—Harbor works at Copenhagen, Denmark. Am Soc Civil Eng Trans v 14, p 212-18.

Möller, M.
1908—Application of reinforced concrete to maritime works; preserving it by the use of trass and slag cement. 11th Cong de Navigation, St. Petersburg, Sec 2, Communication 3.
1909—Use of reinforced concrete beside the sea. Fifth Congress Inter Assoc Test Mat, Copenhagen, XI-3, abstr Eng Rec v 60, p 383.
1910—Eisenbeton am meere. Zement und Beton v 9 p 143-8.

Moncrieff, J. Mitchell.
1923—Portland cement concrete in marine works. Rept to 13th Inter Congress of Navigation, London Concrete. pam 56, p 37-59.

Monnerqué
1886—Ciment à prise prompte de Boulogne-sur Mer et de Desvres. Ann des Ponts et Chaussées ser 6, v 11, p 359-62.

Montaut, L.
1862—Pouzzolane de Santorin. Ann des Ponts et Chaussées ser 4, v 3, p 284-307.

Morrison, G. J.
1899-1900—Cement concrete. Inst Civil Eng Pro v 139, p 340-2.

Mortars for marine constructions.
1866—J Frank Inst v 82, p 56.

Mortars made of lime, sand and puzzo-
1838 lana. J Frank Inst v 25, p 159-66.

Mortier fait avec la pouzzolane artifi-
1809 cielle. Soc de l'Encouragement Bul v 8, p 204.

Mortiers en eau de mer.
1885—Nouvelles Ann de la Constr v 31, p 11-6.

Murray, J.
1855-6—On the progressive construction of the Sunderland docks. Inst Civil Eng Pro v 15, p 418-44, discussion p 445-55.
1858-9—Report of M. Féburier on hydraulic mortars for structures in the sea. Inst Civil Eng Pro v 18, p 136-41.

Naval dry dock at Brooklyn.
1851—J Frank Inst v 51, p 135.

Neate, C.
1891-2—Neapolitan system of constructing sea works with puzzuolana. Inst Civil Eng Pro v 107, p 152-3.

Nehou.
1835—Mortiers hydrauliques et bétons du Calaisis. Ann des Ponts et Chaussées ser 1, v 9, p 105-13.

Newberry, S. B.
1906—Cement that will resist salt water. Cement Age v 3, p 104.
1907—Cement for sea water construction. Cement Age v 4, p 38-41, Eng News v 58, p 645-6.

Newberry, S. B. and W. B.
1897—Constitution of hydraulic cements. J Soc Chem Ind v 16, p 887-93, discussion p 93-4.

New graving dock at Malta.
1867-68—J Frank Inst v 84, p 220, v 85, p 384.

New Jersey freight terminals for the
1916 Port of New York. Eng News v 76, p 90.

Newman, John.
1894—Notes on concrete and works in concrete. Spon, London, rev ed 1904.

New reinforced concrete wharf and jetty
1915 for the Port Talbot Railway and Docks Co. Concrete & Constr Eng v 10, p 601-8.

Nicholson, George F.
1922—Cork harbor development. Purcell, Cork, Ireland.

Nitzsche.
1918—Formation of the double sulphates of Ca and Al in cement and its deleterious action. Zeit angew Chem v 31, p 195-6, Chem Abstr v 13, p 1006.
1919—Behavior of different cements in solutions of sodium and magnesium sulphates of varying concentration. Technik u. Ind 1919, p 81-90, abstr J Soc Chem Ind v 38, p 769A.
1920—Behavior of cement mortars in sulfate-bearing waters. Zement v 9, p 37-40, 50-3, Chim & Ind v 5, p 317, Chem Abstr v 15, p 3190.
1921—Protection of concrete and cement against the action of sulphates by means of barium carbonate. Zement v 10, p 1-2, 13-5, Chim & Ind v 6, p 799, Chem Abstr v 16, p 998.

Noble, A.
1887—Effect of salt water on the strength of cements. Am Soc Civil Eng Trans v 16, p 80.

Noel.
1853—Rapport sur les travaux du bassin de Radoub du port de Gênes. Ann des Ponts et Chaussées ser 3, v 6, p 257-64.
1854—Mortiers à sous-carbonates et mortiers employés à l'eau de mer. Ann des Ponts et Chaussées ser 3, v 7, p 78-86.
1855—Chaux et mortiers. Ann des Ponts et Chaussées ser 3, v 10, p 354-8.
1857—Chaux et mortiers hydrauliques. Ann des Ponts et Chaussées ser 3, v 14, p 361-3.
1857—Mortiers employés à la mer. Ann des Ponts et Chaussées ser 3, v 14, p 340-51.
1858—Mortiers de pouzzolane d'Italie. Ann des Ponts et Chaussées ser 3, v 16, p 374-6.

Norton, F. O.
1880—American natural cement. Am Soc Civil Eng Trans v 9, p 278-86.

Nussbaum, H. C.
1908-9—Use of trass for hydraulic mortars. Inst Civil Eng Pro v 175, p 373.

Observations of effect of sea water on
1921 concrete. Eng News-Rec v 86, p 121-3.

Ocean pier of reinforced concrete at
1912 Long Branch, N. J. Eng Rec v 65, p 521.

Official German recognition of the harm-
1911 less nature of a slag addition to portland cement clinker. Eng News v 66, p 291.

O'Hara, J. M.
1910—Action of sea water on portland cement. Cement & Eng News v 22, p 288, Eng Rec v 61, p 677-8.
1911—Retrogression in the tensile strength of cement. Am Soc Civil Eng Trans v 74, p 398-402, discussion p 403-10.

Olliver.
1828—Sur la préparation de la chaux hydraulique. Soc de l'Encouragement Bul v 27, p 91-3.

Ott, A.
1873—Verwendung der hochofenschlacken zur fabrikation von hydraulischem cement. Dinglers polytech J v 208, p 57-62.

Owens, J. S.
1920—Attrition of concrete surfaces exposed to sea action. Eng & Contr v 53, p 356-7, Surveyor v 57, p 92-3; Engineering v 109, p 215, from Concrete Inst Trans.

Owens, J. S., and **Wood**, F. J.
1911-12—Reinforced concrete sea defences. Inst Civil Eng Pro v 189, p 292-309, abstr Eng Rec v 68, p 240-1.

Pagon, W. W.
1916—Destructive action of sea water on concrete. Eng & Contr v 45, p 469; Eng Rec v 73, p 702; Concrete v 9, p 112; Eng & Min J v 102, p 215-16.

Panama Canal Cristobal coaling plant.
1915—Engineering v 100, p 357-60.

Parandier.
1840—Chaux et ciments hydrauliques, considérations géologiques. Ann des Ponts et Chaussées ser 1, v 19, p 71-127.

Parkes.
1873-4—Inclined blocks of concrete at Kurrachee. Inst Civil Eng Pro v 37, p 364.

Parsons, R. C.
1892-3—Halifax graving dock at Halifax, N. S. Inst Civil Eng Pro v 111, p 41-7.

Pasch.
1829—Preparing hydraulic cement. J Frank Inst v 8, p 16-8.

Pasley, C. W.
1837—Experiments on cements. Inst Civil Eng Pro v 1, p 17-9.

Passow, H.
1908—Verwendung von hochofenschlacken. Metallurgie v 5, p 410-12.
1911-2—Slag cement tests. Inst Civil Eng Pro v 189, p 370-1.
1915—Blast-furnace slag and portland cements. Tonind Zeit v 39, p 759-60; 765-6; 771-2; 775-6; 781-2; 792; Chem Abstr v 10, p 1087.
1916—Hochofenzement und portlandzement im meerwasser und salzhaltigen wässer. Tonind Zeit v 40, p 413-4; 417-8; 423-4; 430-1; 437-8; 443-4.

Paterson, M.
1891-2—Use of ashes in concrete. Inst Civil Eng Pro v 107, p 192.

Pawlowski, Auguste.
1922—L'amélioration des chaux et ciments par la vase marine et les emplois industriels de ce produit. Génie Civil v 8, p 595-6.

Pennsylvania Railroad, Reinforced con-
1916 crete coal pier for. Eng News v 75, p 399.

Petermann.
1922—Beton, randspannungen im rechteckigen, querschnitt auf grund des potenzgesetzes infolge einer normalkraft ausserhalb des kerns. Bauingenieur 1922, p 296.

Petot.
1838—On the preparation of factitious puzzolanas. J Frank Inst v 25, p 289-300.

Petterson, K.
1923—Concrete and reinforced concrete. Report to 13th International Congress of Navigation, London, 18 pp.

Petrographie des portland-cements.
1897—Tonind Zeit v 21, p 1148-51, 1157-9.

Petry.
1922—Gegenwarts und zukunftsfragen des, und eisenbetonbaues auf technisch-wissenschaftlichem gebiet. Bauingenieur 1922, p 97-100.

Petzold.
1841—La pouzzolane artificielle à Alger. Ann des Ponts et Chaussées ser 2, v 1, p 367-72.

Philadelphia's Southwark piers com-
1915 pleted. Eng Rec v 72, p 478-80.

Pier development work at Halifax, Nova Scotia. Cement Wld v 10, no 2, p 27-8.

Pierce, George.
1911—Destructive action of alkali on cement. Min Sci Feb 2, 1911, p 130.

Pimm, G. B. R.
1911-2—Making and driving of reinforced concrete piles. Inst Civil Eng Pro v 189, p 314-8.

Poirel.
1840—Béton, de son emploi pour les fondations à la mer. Soc de l'Encouragement Bul v 39, p 475-6.
1840—Fondations à la mer pour les jettées et les ports. Soc de l'Encouragement Bul v 39, p 475-6.
1841—Mémoires sur les travaux à la mer. Carilian, Paris.

Pope, F. A.
1916—Concrete wharf exposed to sea water and wave action at Fort William, Me. Prof Mem Eng Corps U S Army v 8, p 676-83.

Porte-vitrages en ciment armé, système
1922 Demur. Génie Civil v 80, p 579.

Portland cement in sea water.
1897—Eng Rec v 35, p 331.

Portlandzement, puzzolanzement und
1885 schlackenmehl. Zeit Ver deut Ing v 29, p 734-5.

Posselt, E.
1922—El cemento de Sierras Bayas. La Ingenieria v 26, p 604-8.

Potter, C. J.
1909—Chemical changes in portland cement concrete and the action of sea water thereon. J Soc Chem Ind v 28, p 6-10, discussion p 10.

Poulsen, A.
1907—Anwnedung von "Moler" einer in Dänemark natürlich vorkommenden, sehr reinen kieselgur, als zuschlag, für zement im meerwasser. Beton und Eisen, v 6, p 27, abstr Ingeniören no 29 & 30, 1906.
1909—Cement in sea water. Pamphlet (in English) by Assoc Scandinavian Portland Cement Manuf. Inter Assoc Test Mat Pro 1909; Int Assoc Test Mat Bul XI-4, abstr Cement Age v 10, p 184, v 11, p 380, Eng News v 64, p 3, Concrete & Constr Eng v 5, p 23, Eng & Contr v 34, p 51-2, Chem Abstr v 4, p 1094.
1912—Diatom-earth as pozzolana for cement. Inter Assoc Test Mat, 6th Congress, paper XVI-1.
1914-5—Experiments on mortar and diatomaceous earth as puzzolana in sea water with special reference to Groynes in Denmark. Inst Civil Eng Pro v 200, p 409-20.
1923—Report to 13th International Congress of Navigation, London, Concrete.

Pouzzolanes, Essai des.
1896—Soc de l'Encouragement Bul ser 5, v 1, p 94-5.

Powell, F. E.
1916—Concrete piles 100 feet long. Eng News v 75, p 1177-8.
1916—Large concrete piles. Concrete & Const Eng v 11, p 31-4.

Powers, M. I.
1891—Effect of salt in mixing cement mortars. Eng News v 26, p 481.

Preston, F. J.
1897-8—Cement concrete. Inst Civil Eng Pro v 132, p 355-8.

Price, W. H.
1875-6—The Manora breakwater, Kurrachee. Inst Civil Eng Pro v 43, p 1-52.
1891-2—Concrete blocks at Kurrachee. Inst Civil Eng Pro v 107, p 193-5.

Probst, E.
1912—Destruction of concrete between tides in sea water. Eng News v 68, p 262.

Proposal for establishing a standard SO_3 1912 content for portland cement. Inter Assoc Test Mat v 2, pt 2, sec XVII-4.

Prucha, J.
1875-6—On the use of santorin in the construction of hydraulic works on the sea coast. Inst Civil Eng Pro v 45, p 291-5.

Puzzolan cement, Proper uses of.
1906—Eng News v 56, p 408-9.

Raffeneau de Lile.
1841—La pouzzolane artificielle à Alger. Ann des Ponts et Chaussées ser 2, v 1, p 373-84.

Rankin, G. A.
1916—Portland cement. J Frank Inst v 181, p 747-84.
1915—Ternary system $CaO-Al_2O_3-SiO_2$ Am J Sci v 39, p 1-79.

Ransome.
1880—Utilization des laitiers des hauts-fourneaux. Ann des Ponts et Chaussées ser 5, v 20, p 331-2.

Ravier.
1854—Mortiers employés en eau de mer à Alger. Ann des Ponts et Chaussées ser 3, v 8, p 20-80.

Rebuffat, Orazio.
1900—Action de l'eau de mer sur les mortiers à pouzzolane. Ann des Ponts et Chaussées ser 7, v 10, pt 4, p 293.
1900—Azione dell'acqua del mare sulle malte a pozzolana. Gaz Chim Italiana v 30, pt 2, p 157-64.
1901—I solfoalluminate di calcio e la decomposizione delle construzione marittime eseguite in cemento Portland. Gaz Chim Italiana v 31, no 1, p 55-7, v 32, no 2, p 158-68.

Redgrave, G. R., and **Spackman,** C.
1905—Effect of sea water on cement. Calcareous cements. Griffin & Co., London. 310 pp.

Reinforced concrete for structures ex-1920 posed to sea water. Cement & Constr Eng March 1920, p 41, Concrete v 16 (Cement Mill Section), p 48, Chem Abstr v 14, p 2694.

Reinforced concrete in salt water. Con-1908 crete Eng v 3, p 158, Chem Abstr v 2, p 2144.

Reinforced concrete in sea water. Con-1912 crete Cement Age v 1, p 31.

Reinforced concrete in sea water, Use 1912 of. Report of special committee, Government of Netherlands. Eng News v 68, p 1229, Génie Civil v 62, p 98.

Reinforcing value of gunite encasing for 1923 steel beams. Canadian Eng v 44, p 361-2.

Rennie, J.
1845—On the ancient harbour of Ostia. Inst Civil Eng Pro v 4, p 307-23.
1846—Construction of harbours. Inst Civil Eng Pro v 5, p 37-41.
1846—Roman cement. Inst Civil Eng Pro v 5, p 35.
1856-7—On the employment of rubble beton or concrete in works of engineering and architecture. Inst Civil Eng Pro v 16, p 423-35, discussion p 436-48.

Report by Brussels commission on hy-1894-5 draulic materials, trass cement, etc. Inst Civil Eng Pro v 122, p 418-9.

Report of a committee on action of sea 1907 water on concrete. Ry Supt Bridges & Bldgs Pro v 17, p 175-8, abstr Ry Gaz v 43, p 565-6, Cement Age v 5, p 397-9, 350-2, Eng News v 58, p 461, Chem Abstr v 2, p 582.

Report of Committee C-6 on drain tile. 1923—Am Soc Test Mat Pro v 23, pt 1, p 198-207.

Report of committee on the action of sea 1897 water on cement. Eng News v 37, p 117, v 38, p 67-70.

Report of joint committee on concrete 1917 and reinforced concrete. Am Soc Civil Eng Trans v 81, p 1100-52, discussion p 1153-1206, abstr Eng News-Rec v 79, p 1126-7.

Report on condition of concrete struc-1917 tures in sea water, Navy Yard, Mare Island, Cal. Public Works of the Navy bul no 28, October, 1917, p 37-47.

Report on condition of concrete struc-1917 tures in sea water, Navy Yard, New York. Public Works of the Navy bul no 28, October, 1917, p 20-30.

Report on condition of concrete struc-1917 tures in sea water, Navy Yard, Portsmouth, N. H. Public Works of the Navy bul no 28, October, 1917, p 31-7.

Résistance des matériaux hydrauliques 1900 à la mer. Ann des Trav Pub de Belg v 5, p 1177-81.

Rhett, A. H.
1918—Porosity the vital point to consider. (Comment on Wig and Ferguson article.) Eng News-Rec v 80, p 265-7.

Richardson, Clifford.
1911—Action of sea water on portland cement. Eng Rec v 61, p 741-2, Chem Abstr v 5, p 367.

Richardson, R. D.
1911—Action of mine water on concrete. Eng Rec v 63, p 75.

Ridley, C. S.
1917—Subaqueous concrete work on the Cape Fear River, N. C. Prof Mem Eng Corps U S Army v 9, no 43, p 23-33.

Riissager, F., and **Dyckerhoff,** R.
1909—Zement im meerwasser. Tonind Zeit v 33, p 1234-5.

Ringers, J. A., and **Tellegen,** C.
1923—Concrete and reinforced concrete. Report to 13th International Congress of Navigation, London. 19 pp.

Ritter, F.
1864—Verhalten einiger cem. v hydraul. kalke gegen meerwasser. Allgemeine Bauzeitung 1864, v 29, p 287-90.

Robertson, G.
1857-8—Pozzuolana mortar. Inst Civil Eng Pro v 17, p 420.
1862—Concrete used in the London docks. J Frank Inst v 73, p 163-6.

Rodt, V.
1915—Über das verhalten von portlandzementmörteln in verschiedenen salzlösungen. Mitt Königl Materialprüfungsamt v 33, p 229-40, abstr J Soc Chem Ind v 35, p 541.

Roeder, W.
1916—Zemente in schwefelsäurehaltigem wasser. Tonind Zeit v 40, p 664, Chem Abstr v 11, p 2032-3.

Rohland.
1903—Einwirkung des meerwassers auf portlandzement. Thonind Zeit v 27, p 2022-5.
1905—Candlotsche reaktion und die verwendung des portlandzementes bei meerwasserbauten. Tonind Zeit v 29, p 1599-1600.

Ross, J.
1919—Concrete in sea water. Waterproofing engineering, Wiley, N. Y. p 403-7.

Roth, Ludwig.
1882—Der bauxite und seine verwendung zur herstellung von cement aus hochofenschlacke. Zeit Ver Deut Ing v 26, p 727-8.

Rout, T. J.
1916—Building concrete lighthouse on Brandywine Shoal. Eng News v 75, p 928-31.

Russell, J. S.
1847—Breakwaters and sea walls. J Frank Inst v 44, p 13-5.

Saec.
1867—Mortier et ciment. Soc de l'Encouragement Bul v 66, p 287.

Sandeman, J. W.
1894-5—Portland cement and concrete. Inst Civil Eng Pro v 121, p 214-25.
1906—Action of sea water upon concrete. Engineering v 81, p 1-2, abstr Sci Am Sup v 61, p 25186-7.

San Francisco Bay marine piling com-
1921 mittee. Second Report of committee published by Am Wood Preservers' Assoc.

Santa Monica pier failure due to perme-
1920 able concrete. Eng & Contr v 53, p 110-1, Eng News-Rec v 84, p 621-3.

Sauvage.
1846—Pouzzolane naturelle découverte dans le département des Ardennes. Soc de l'Encouragement Bul v 45, p 249-50.

Saville, C. M.
1911—Action of sea water on concrete blocks, Cristobal, Canal Zone. Harvard Eng J v 9, p 197.

Saville, L. H.
1921—Reason for deterioration of reinforced concrete structures above mean tide level. Engineering v 112, p 73-4, Chem Abstr v 16, p 624.

Scarborough's new sea wall and prome-
1887 nade. Engineer v 63, p 28.

Scheme of the Boston harbor tests on
1908 the effect of sea water on concrete. Eng News v 60, p 730.

Schiffner.
1899—Einfluss der kohlensäure auf portland cement und trassmörtel. Tonind Zeit v 23, p 909-12.

Schlackenzement und meerwasser. To-
1906 nind Zeit v 30, p 440-4.

Schlesischer trass. Dinglers polytech J
1860 v 157, p 394-6.

Schmidt, Max E.
1879—South pass jetties. Notes on the consolidation and durability of the works with a description of the blocks and other constructions of the last year. Am Soc Civil Eng Trans v 8, p 189-226.

Schott, O.
1911—Amerikanische portlandzementbetonprüfungen im meerwasser. Chem Zeit v 35, p 256.

Schuliatschenko.
1899—Einwirkung des meerwassers auf die hydraulischen bindemittel. Tonind Zeit v 23, p 913-5, 948-50, v 25, p 1051-4.
1903—Bericht der meerwasserkommission. Tonind Zeit v 27, p 1227-31.

Schumann, C
1885-6—Blast furnace slag and slag cement as compared with portland cement. Inst Civil Eng Pro v 85, p 415-6, from Deutsche Bauzeitung.

Schwartze.
1867—Ciments très-durs et très-résistants. Soc de l'Encouragement Bul ser 2, v 14, p 727.

Schwarz, E.
1907—Osmose und portlandzement. Beitrag meerwasserfrage des portlandzementes. Tonind Zeit v 31, p 1794-5.
1898—Zur meerwasserfrage des portlandzements. Tonind Zeit v 22, p 1279-80.

Scott, Adam.
1894-5—Deepwater quays at New Castle-on-Tyne. Inst Civil Eng Pro v 119, p 291-7.

Scott, M.
1858-60—Description of a breakwater at the Port of Blyth. Inst Civil Eng Pro v 18, p 72-90, discussion p 91-161, v 19, p 644-50, discussion p 651-74.

Sea wall at Boston Harbor. Am Soc 1878 Civil Eng Trans v 7, p 21-3.

Seaman, J. W.
1916—Concrete sheet pile groin at Long Branch, N. J. Eng News v 75, p 650-1.

Searle, A. B.
1914—Effect of sea water on concrete. (In cement, concrete and bricks) Van Nostrand, 1914, p 264.

Sears, Clinton B.
1876—Principles of tidal harbor improvements as applied at Wilmington, Calif. Am Soc Civil Eng Trans v 5, p 388-426.

Seiler, J. F.
1923—Wrapping concrete bridge abutments in an asphalt blanket. Munic & County Eng v 64, p 135-6.

Semple, Geo.
1776—Treatise on building in water. Dublin.

Sewell, J. S.
1912—Reinforced concrete in hydraulic works. Eng News v 67, p 1029-31.

Shaw, A. L.
1919—Volcanic tuff and its uses. Prof Mem Eng Corps U S Army v 11, p 430-42.

Shertzer, T. B.
1921—Lime in construction. Nat Lime Assoc Bul 306, Washington, D. C. 80 pp.

Shima, S.
1905—Concrete blocks at Osaka harbor works. Am Soc Civil Eng Trans v 54, pt A, p 221-36, abstr Cement Age v 1, p 542.

Shiraishi, N.
1906—New graving dock at Nagasaki, Japan. Am Soc Civil Eng Trans v 56, p 73-8, discussion p 79-91.

Slag cement. J Frank Inst v 110, p 57-9. 1880

Smeaton, J.
1791—Narrative of the building of the Edystone lighthouse. Book IV. Pub by author. London.

Smith, O.
1803—Mortier pour les constructions preparé avec le ciment romain. Soc de l'Encouragement Bul v 2, p 169-74, 177-80.

Smith, G. A. and **Slater,** W. A.
1923—Inundation methods for measurements of sand. Canadian Eng v 44, p 376-80, Eng News-Rec v 90, p 216.

Smith, G.
1880—Effect of sulphates on lime. Am Gas Light J v 33, p 130-1, from Builder.

Smith, M.
1804-5—Note sur le ciment romain. Soc de l'Encouragement Bul v 2, p 169-72, 177-80.

Smith, W.
1891-2—Influence of sea water upon portland cement mortar and concrete. Inst Civil Eng Pro v 107, p 73-97, discussion p 98-198.

Snow, W. A.
1921—Pronounced reinforcement corrosion due to sea water or electrolysis. Eng News-Rec v 87, p 528-9, Chem Abstr v 16, p 325.

Soares, Alfonso J. N.
1893—Leixoes harbor, A brief account of its building. Am Soc Civil Eng Trans v 29, p 194-201.

Spackman, Henry S.
1909—Calcium aluminates, their effect on mortars. J Frank Inst v 167, p 186-204.
1910—Aluminates in cement manufacture. Am Soc Test Mat Pro v 10, p 315-23, discussion p 324-7, 359.
1911—Relation of the lime content of cement to the durability of concrete. Nat Assoc Cement Users Pro v 7, p 640-4, discussion p 645-6.

Special committee on concrete and rein-1917-8 forced concrete, Final report of. Am Soc Civil Eng Trans v 81, p 1101-52, discussion p 1153-1206, v 82, p 1541-76.

Special committee on uniform tests of 1912 cement, Final report of. Am Soc Civil Eng Trans v 75, p 665-96.

Specifications and methods of tests of 1918 portland cement. Am Soc Civil Eng Trans v 82, p 166-84.

Specifications for portland cement. Am 1897 Soc Civil Eng Trans v 37, p 314-5.

Spiegelberg.
1909—Einwirkung von gips und kalziumchlorid auf zement. Tonind Zeit v 33, p 1289-90, abstr J Soc Chem Ind v 28, p 1131.

Spiller, John.
1868—Analysis of the ancient Roman mortar of the castrum of Burgh, Suffolk. Engineer v 26, p 185.

Sprenger, J. J. I.
1923—Samenstelling van gewapend beton voor werken in zeewater. De Ingenieur v 38, p 738-40.

Spring, F. J. E.
1910-1—Light reinforced concrete wharfing used in the port of Madras. Inst Civil Eng Pro v 186, p 427-33.

Springer, F. J.
1916—Concrete piles in salt water. Sci Am v 115, p 147, 159.

Squire, H. E.
1918—Concrete in sea water in San Francisco harbor. Eng News-Rec v 80, p 575-7.

Stanford, H. R.
1913—Use of concrete in U. S. Navy. Nat Assoc Cement Users Pro v 9, p 266, abstr Concrete Cement Age v 2, p 228, 242.
1916—Concrete used in construction of Pearl harbor dry dock. Am Soc Civil Eng Trans v 80, p 248-57.

Stanger, W. H. and **Blount,** B.
1900-1—Rotary process of cement manufacture. Inst Civil Eng Pro v 145, p 44-72, discussion p 73-136.

Stanglmayr.
1922—Beton und eisenbetonarbeiten an der Mittleren Isar. Bauingenieur v 3, p 334-42.

Stanford, C. W.
1914—Modern pier construction in New York harbor. Am Soc Civil Eng Trans v 77, p 503-21, discussion p 522-63.

Stanley, G. L.
1906—Use of salt in concrete sidewalk construction. Nat Assoc Cement Users Pro v 2, p 284-7.

Stephan, Erich.
1910—Betonzerstörung durch schwefelwasserstoffgas. Beton und Eisen v 9, p 22-4.

Stephenson, R.
1847—Construction of sea walls and embankments. Inst Civil Eng Pro v 6, p 115-7.

Stern, E.
1909—Kleingefüge des portlandzementes. Mitt Königl Materialprüfungsamt v 27, p 7-16.

Stevenson, C. A.
1891-2—Instances of successful use of portland cement concrete in sea works. Inst Civil Eng Pro v 106, p 196-7.

Stiefel, H. C.
1905—Action of boiling saline solutions on cement composition. Cement Age v 1, p 493-5.

Stoney, B. B.
1862—Action of sea water on lime mortar. Inst Civil Eng of Ireland Trans v 7, p 90-6, Engineer v 13, p 311.
1873-4—Construction of harbor and marine works with artificial blocks of large size. Inst Civil Eng Pro v 37, p 332-55, discussion p 356-80.
1886-7—Concrete works in Dublin harbour. Inst Civil Eng Pro v 87, p 229-31.

Strebel.
1921—Behavior of cement in solutions of calcium sulphate. Zement v 10, p 385-6, 397-8, 409-11, 421-3, abstr J Soc Chem Ind v 40, p 848A.

Strype, W. G.
1886-7—Wicklow harbour improvements. Inst Civil Eng Pro v 87, p 114-22.

Study of failures of concrete structures. 1918 Am Ry Eng Assoc Bul v 20, no 211.

Swainson, J. H.
1889-90—Caliope graving dock at Auckland, N. Z. Inst Civil Eng Pro v 101, p 211-7.

Taft, H. S.
1914—Chemistry of salt water cement. Eng Club Baltimore J v 3, no 4, p 12-7, Chem & Met Eng v 12, p 26-30, Chem Abstr v 8, p 811.
1915—Use of wood and concrete in structures standing in sea water. Inter Eng Congr Trans, Materials of Eng vol, p 321-64, Chem Abstr v 9, p 3346.
1915—Reinforced concrete docks. Am Soc Civil Eng Trans v 78, p 1058-111, discussion p 1112-38.
1916—Effect of salt water on concrete. Am Soc Civil Eng Trans v 80, p 297-302.

Talbot, Arthur N. and **Richart,** Frank E.
1923—Strength of concrete—its relation to cement aggregates and water. Illinois U Eng Expt Sta bul no 137, v 21, no 7.

Tensile strength of briquets mixed and 1874-5 stored in sea water. Inst Civil Eng Pro v 41, p 132-4, 154.

Terry, C. A.
1916—Galvan Port, Bahia Blanca, Argentine. Concrete & Const Eng v 11, p 44-6.

Tests of cements. Conclusions adopted 1897 by the French Commission. Eng Rec v 36, p 118-9, 160-3, 182-4.

Tests of concrete immersed in sea water. 1909 Canadian Eng v 16, p 71-2.

Tests on concrete in sea water. Eng 1908-9 News v 60, p 503-4, 730, v 62, p 419, abstr Cement Age v 9, p 324.

Thacher, E.
1908—Effect of sea water upon concrete. Am Soc Civil Eng Trans v 61, p 42-6, Cement v 8, p 472-4.

Thackara, A. W.
1908—Report on iron ore cement. U S Consular Reports, June, no 333, p 165-8.
1908—Iron ore cement in Germany. Eng News v 59, p 702-3.

Thomas, Wm. N.
1920-1—Cement and concrete, Effect of sugar on. Inst Civil Eng Pro v 212, p 414-23.

Thomassin.
1835—Béton, son application à la construction des chemins de fer. Soc de l'Encouragement Bul v 34, p 228.

Thompson, Sanford E.
1915—Concrete aggregates. Int Eng Cong Trans San Francisco, Materials of Engineering Construction p 194-219, discussion p 219-22.

Thompson, W. E.
1923—Effects of grouting and gravel packing around tunnel. Eng News-Rec v 90, p 617-9.

Thorvaldson, T.
1922—Chemistry of portland cement and its disintegration by alkaline ground waters. Engng J v 5, p 457-60.

Torpedo-boat berth at the Charleston 1915 Navy Yard. Eng News v 74, p 872-3.

Totten, J. G.
1838—Lime, hydraulic cement, sand, mortar making, etc. J Frank Inst v 26, p 1-26.

Towle, H. E.
1870-1—American cement Rosendale. Inst Civil Eng Pro v 32, p 307-8.

Treussart.
1827—Preparation of hydraulic cements. J Frank Inst v 3, p 355-6. from Ann de Chimie et de Physique.

Turkish recipes for hydraulic cement. 1854 J Frank Inst v 58, p 409-10, from Mechanic's Mag.

Turneaure, F. E.
1918—Spalling of reinforced concrete in moist locations. Eng News-Rec v 80, p 46-7.

Turner, H. C.
1904—Experiments on concrete as a preservative of steel exposed to sea water. Eng Rec v 50 p 146, Eng News v 62, p 153, Tonind Zeit v 28, p 1526.

Tuttle, A. S.
1921—Use of reinforced concrete in or near sea water. Pamphlet by Board of Estimate and Apportionment, New York City. Mun Eng J v 7, p 66-84, Eng News-Rec v 86, p 1032, 1018, Eng & Contr v 56, p 487-8.
1908—Decomposition of concrete in sea water, Eng News v 60, p 341-2, 503-4.

Tuttle, M. C.
1911—Concrete test specimens in sea water at Charleston Navy Yard. Eng Rec v 64, p 229-31; Cement Age v 13, p 155-7.

Twelvetrees, W. N.
1922—Reinforced concrete piers and marine borers. Canadian Eng v 43, p 374-6, from Concrete Inst J.

Twenty-five-hundred ton concrete cribs
1916 are built and launched in a "shipyard." Eng Rec v 73, p 73-4.

Twigg, R. H.
1899-1900—Penzance harbour and docks. Inst Civil Eng Pro v 139, p 295-301.

U. S. Bureau of Yards and Docks. Ac-
1921 tivities of the Bureau of Yards and Docks, Navy Department, World War, 1917-1918. Government Printing Office, Washington.

Unna.
1899—Die bestimmung rationeller mörtelmischungen unter zugrundellegung der festigkeit, dichtigkeit und kosten des mörtels. Köln a Rh.

Untersuchungen über erhärtung vom
1923 zement nach einwirkung niedriger temperaturen. Zentr d Bauverwaltung v 43, p 198.

Untersuchungen über silikat und kar-
1907 bonatbildung in mörteln des altertums. Tonind Zeit v 31, p 834-6.

Use of reinforced concrete in engineer-
1908 ing structures. Am Soc Civil Eng Trans v 61, p 35-72.

Utilization of trass mixed with hydrau-
1899 lic cement in Germany. Eng News v 42, p 62-3.

Utilization of volcanic products. En-
1899 gineer v 87, p 525-6.

Valparaiso port works. Engineer v 121,
1916 p 190-1.

Van den Thoorn, N. A. M.
1897-8—Ymuiden harbor improvements. Inst Civil Eng Pro v 132, p 412.

Van Heemskerck van Beest, J. E.
1923—Korte mededeelingen over den bouw van kademuren in het Amsterdamsch havengebied. De Ingenieur v 38, p 349-54.

Van Kuffeler, V. I. P. de Blocq.
1912—Action of sea water on reinforced concrete. Inter Assoc Test Mat 1912, XVII-3, discussion B, p 78, abstr Eng News v 68, p 517.

Van Lidth de Jeude, O. C. A.
1912—Beton in zeewater. De Ingenieur v 27, p 773-5.

Vaudrey.
1857—Emploi du ciment de portland au pont Saint Michel. Ann des Ponts et Chaussées ser 3, v 14, p 367-70.

Venice, California, best protected by
1916 permanent sea wall and low groins, Shore at. Eng Rec v 73, p 51-4.

Verbesserung des portlandzementes für
1904 meeresbauten durch zusatz puzzolonartiger stoffe. Tonind Zeit v 28, p 589-90.

Verein Deutscher Portlandzement Fab-
1912 rikanten. Proposel for establishing a standard SO_3 content for portland cement. Inter Assoc Test Mat Pro XVII-4 (10), discussion B, p 54.

Verhalten der hydraulischen bindemittel
1896 zum meerwasser. Tonind Zeit v 20, p 838-40.

Vergleichende untersuchungen von port-
1892 land-pozzolan und romanzementen. Zeit Ver deut Ing v 36, p 258.

Vernon-Harcourt, L. F.
1879-80—Dock walls wholly constructed of concrete. Inst Civil Eng Pro v 62, p 192-4.

Verrill, G. E.
1917—Breakwaters and jetty construction in the New London, Conn., district. Prof Mem Eng Corps U S Army v 9, p 1-22.

Vetillart, H., and **Feret,** R.
1908—Additions de pouzzolanes aux mortiers en prise à l'eau de mer. Ann des Ponts et Chaussées ser 8, v 31, p 121-34.

Vicat, L. J.
1818—Treatise on mortars and cements. Paris, Goujon.
1824—Chaux hydraulique, ses propriétés et sa préparation. Soc de l'Encouragement Bul v 22, p 282, v 23, p 132-46.
1826—Cements. J Frank Inst v 2, p 371-2.
1832—Sur les causes de la compression dont les mortiers ou ciments calcaires sont susceptibles. Ann des Ponts et Chaussées ser 1, v 4, p 257-60.
1834-46—Chaux et ciments hydrauliques (recherches statistiques). Ann des Ponts et Chaussées ser 1, v 7, p 224-35, v 8, p 371-7, v 9, p 357-72, v 12, p 129-46, v 14, p 334-45, v 18, p 227-52, v 19, p 368-82, ser 2, v 2, p 35-44, v 3, p 118-26, v 5, p 116-25, v 7, p 257-64, v 10, p 121-8, v 11, p 378-84.
1836-42—Sur une fabrication de pouzzolane à Argentat. Ann des Ponts et Chaussées ser 1, v 12, p 96-9.
1838—Chaux hydrauliques magnésiennes. Ann des Ponts et Chaussées ser 1, v 15, p 375-7. J Frank Inst v 25, p 338-9.

1839—Pouzzolanes pour jetées à la mer. Ann des Ponts et Chaussées ser 1, v 18, p 251-2.

1841—Effect de la cuisson sur les ciments. Soc de l'Encouragement Bul v 40, p 59-60.

1842—Sur les pouzzolanes artificielles. Ann des Ponts et Chaussées, ser 2, v 4, p 135-7.

1843—Action de l'eau de mer sur les bétons. Soc de l'Encouragement Bul v 42, p 483-4.

1843—Mortier de pouzzolane, action de l'eau de mer sur. Ann des Ponts et Chaussées, ser 2, v 6, p 232-3.

1846—Constructions hydrauliques perfectionnées. Soc de l'Encouragement Bul v 45, p 92.

1846—Pouzzolane artificielle composée. Soc de l'Encouragement Bul v 45, p 94.

1846—Pouzzolane naturelle non-volcanique. Ann des Ponts et Chaussées, ser 2, v 12, p 127-8.

1847—Découverte d'une pouzzolane naturelle. Ann des Ponts et Chaussées ser 2, v 14, p 78-80.

1849—Pouzzolanes volcaniques. Ann des Ponts et Chaussées ser 2, v 18, p 257-89.

1851—Ciments éventés et brûlés. Ann des Ponts et Chaussées ser 3, v 1, p 236-54.

1852—Appréciation de la valeur hydraulique des matériaux pour travaux à la mer. Ann des Ponts et Chaussées ser 3, v 3, p 379-81.

1852—L'emploi du trass comme pouzzolane dans les travaux à la mer. Ann des Ponts et Chaussées, ser 3, v 3, p 377-9.

1853—Chaux hydraulique. Soc de l'Encouragement Bul v 52, p 121.

1853—Chaux hydraulique artificielle de double et de simple cuisson. Ann des Ponts et Chaussées, ser 3, v 5, p 220-1.

1853—Eau de mer: action qu'elle exerce sur les mortiers hydrauliques. Ann des Ponts et Chaussées ser 3, v 5, p 188.

1853—Constructions dans l'eau de mer. Ann des Ponts et Chaussées ser 3, v 5, p 196-8.

1853-4—Chaux et mortiers. Ann des Ponts et Chaussées ser 3, v 5, p 348-9, v 7, p 28-31.

1854—Chaux et mortiers à la mer. Ann des Ponts et Chaussées ser 3, v 8, p 8-80.

1854—Immersion de béton laitance. Ann des Ponts et Chaussées ser 3, v 8, p 203-5.

1854—Mortiers à la mer. Ann des Ponts et Chaussées ser 3, v 8, p 371-5.

1854—Sur l'opportunité de certaines matériaux pour les travaux à la mer. Ann des Ponts et Chaussées ser 3, v 18, p 232-5.

1855—Mortier magnésien. Ann des Ponts et Chaussées ser 3, v 10, p 354.

1856—Concours relatif aux mortiers hydrauliques destinés à être employés à la mer. Soc de l'Encouragement Bul v 55, p 610-1.

1856-7—Mortiers hydrauliques. Soc de l'Encouragement Bul v 55, p 611; v 56, p 507.

1857—Mortiers employés à la mer. Ann des Ponts et Chaussées ser 3. v 14, p 320-36.

1858—Observations on cement in sea water. Pamphlet Abstr Inter Assoc Test Mat Pro 1912, XVII-2, p 3.

Vicat sur la pouzzolane, Travaux de.
1845—Soc de l'Encouragement Bul v 44, p 202.

Viennot.
1900—Die einwirkung des meerwassers auf mörtel. Tonind Zeit v 21, p 128.

Villeneuve.
1850—Chaux, de son hydraulicité. Soc de l'Encouragement Bul v 49, p 467-9.

Voisin.
1923—Concrete and reinforced concrete. Report to 13th Inter Congress of Navigation, London, 19 pp.

Voisin, J., and others.
1908—Means of preserving reinforced concrete in sea water. 11th Inter Congress of Navigation, St. Petersburg, 1908, p 260-71.

Wagoner, L.
1909—Notes on docks and harbors. Am Soc Civil Eng Trans v 62, p 135-48, discussion p 149-56.

Wallace, Wm.
1865—Ancient mortars. J Frank Inst v 79, p 409-11, Soc de l'Encouragement Bul v 65, p 186-9.

Warner, E. H.
1909—Reinforced concrete pier, Santa Monica, Calif. Eng News v 62, p 633.

Washburn, Edward W.
1921—Porosity and the mechanism of absorption. Am Ceramic Soc J v 4, p 916-22.

Washburn, Edward W., and **Bunting,** Elmer N.
1921—Use of petroleum products as absorption liquids. Am Ceramic Soc J v 4, p 983-9.

1922—Recommended procedures for determining porosity by methods of absorption. Am Ceramic Soc J v 5, p 48-56.

1922—Determination of porosity by the method of gas expansion. Am Ceramic Soc J v 5, p 112-29.

1922—Determination of the porosity of highly vitrified bodies. Am Ceramic Soc J v 5, p 527-37.

Washburn, Edward W., and **Footitt,** Frank.
1921—Water as an absorption liquid. Am Ceramic Soc J v 4, p 961-82.

Wason, L. C.
1914—Progress report on tests of concrete in sea water at Charlestown Navy Yard. Concrete Cement Age v 4, p 273-4, Eng Rec v 69, p 344-6, Eng & Contr v 41, p 516-8.

1923—Tests of concrete in sea water. Am Soc Civil Eng Trans v 86, p 447-54.

Waterbury, L. A.
1910—Failure of concrete piles under ocean pier at Long Beach, Cal. Eng News v 64, p 67.

Watkins, J. E.
1891—Ancient harbors. Am Soc Civil Eng Trans v 24, p 323-5.

Wear of the inter-tidal space on concrete marine structures. Eng
1907 News v 58, p 65-6, 472, Chem Abstr v 2, p 172.

Weller, J. L.
1918—Sea water concrete not hopeless. Eng News-Rec v 80, p 264.

Wentworth-Shields, F. E.
1913-4—Empress dock wall failure, Southampton. Inst Civil Eng Pro v 195, p 71.
1921—Methods of protecting reinforced concrete from marine deterioration. Engineering v 112, p 73, Eng & Contr v 57, p 318, Chem Abstr v 16, p 624.

White, Alfred H.
1915—Volume changes in concrete. Inter Eng Congr, San Francisco. Materials of Eng vol p 242-73.
1923—Integral waterproofings for concrete. Ind & Eng Chem v 15, p 150-3.

White, G. F.
1851-2—Size and composition of concrete blocks at Cherbourg. Inst Civil Eng Pro v 11, p 488-9.
1851-2—Natural cements. Inst Civil Eng Pro v 11, p 504.
1852—Artificial hydraulic or portland cement. J Frank Inst v 54, p 159-60.

Whittemore, G. F.
1916—Construction of concrete block at end of south jetty, Humboldt Bay, Cal. Prof Mem Corps Engr U S Army v 8, p 31-41.

Wig, R. J., and **Ferguson**, L. R.
1917—Examination of concrete structures in sea water. Eng News-Rec v 79, p 532-5, 641-5, 689-93, 737-41, 794-8, discussion Eng News-Rec v 80, p 267.

Wig, R. J., and **Hollister**, S. C.
1918—Problems arising in the design and construction of reinforced concrete ships. Am Concrete Inst Pro v 14, p 441-64.

Willet, J.
1886-7—Concrete above low water at Fraserburg harbor. Inst Civil Eng Pro v 87, p 125.

Williams, A. E.
1912—Iron ore cement. Nat Assoc Cement Users Pro v 8, p 597-612, discussion p 613-15.

Williams, E. L.
1891-2—Portland cement mortar at the Dover Admiralty pier. Inst Civil Eng Pro v 107, p 102.

Williams, G. M.
1922—Durability of concrete in alkali soils. Canadian Eng v 43, p 533-4.
1923—Behavior of concrete exposed to alkaline conditions. Am Soc Test Mat Pro v 23, p 205-10, discussion p 211-47.

Williams, J. E.
1878-9—Whitehaven harbour and dock works. Inst Civil Eng Pro v 55, p 36-48.

Willis, S. C.
1911—Condition of concrete structures in Boston Harbor. Eng Rec v 64, p 271-2.

Witt, J. C.
1918—Influence of certain substances on cement and concrete. Philippine J Sci v 13, sect A, p 29-48.
1920—Effect of calcium sulphate on cement. Eng Wld v 16, p 83-7.
1921—Study of portland cement by chemical analysis. Eng News-Rec v 87, p 650-2.

Witt, J. C. and **Reyes**, F. D.
1917—Effect of calcium sulphate on cement. Philippine J Sci v 12, sect A, p 133-43.

Wolle, R.
1899—Zerstörung des cementbetons durch kohlensäurehaltiges wasser. Uhland's Technische Rundschau pt 2, p 93-4.

Wortman, H.
1905—Harbor development in Holland. Am Soc Civil Eng Trans v 54, pt A, p 181-98.

Yamasaki, G.
1903—New graving dock of the Kawasaki Dock Yard Co. at Kobe. Japan. Eng News v 50, p 257-61.

Yates, J. J.
1917—Action of sea water on concrete bridge. Am Soc Civil Eng Trans v 81, p 677-82.
1919—Report on disintegrating of concrete and corrosion of reinforcing materials in connection with the use of concrete in sea water. Am Ry Eng Assoc Bul v 20, p 707-11.

Yoshida, Tokujiro.
1921—Studies on cooling of fresh concrete in freezing weather. Illinois U Eng Expt Sta Bul 123.

METAL IN SEA WATER

Andrews, T.
1884-5—Corrosion of metals during long exposure in sea water. Inst Civil Eng Pro v 82, p 281-94.

Atlantic City steel pier.
1899—Eng Rec v 40, p 94-6.

Bidwell, H. S.
1905-6—Steel sheet-piling in the Hod Barrow sea wall. Inst Civil Eng Pro v 165, p 165-6.

Binnie, A. R.
1904-5—Action of lime and portland cement on iron and steel. Inst Civil Eng Pro v 161, p 154-5.

Brande.
1842—Changes of cast iron in salt water. Inst Civil Eng Pro v 2, p 153.
1844-8—Composition of iron softened by sea water. Inst Civil Eng Pro v 3, p 87; v 7, p 157.

Calvert, F. C., and **Johnson,** R.
1866—Action of sea water on metals. J Frank Inst v 81, p 25-7, from Mechanics' Mag.

Cargill, Thomas.
1878—Promenade pier, Aldborough, Suffolk. Engineer v 96, p 182-4.

Coe, W. W.
1892—Description of iron coal pier, Norfolk and Western Railroad, Lamberts Point, Norfolk, Virginia, and some of the methods used in its construction. Am Soc Civil Eng Trans v 27, p 124-8; discussion p 129-72.

Colson, C.
1880-1—Portsmouth dockyard extension works. Inst Civil Eng Pro v 64, p 118-73.

Colson, C., and C. H.
1893-4—Hamilton graving dock at Malta. Inst Civil Eng Pro v 115, p 360-80.

Construction of the Old Orchard pier.
1899—Eng Rec v 39, p 228-9.

Davies, J. V.
1923—Graphitic corrosion of cast iron. Annual Rept Eng Foundation, publication 6, p 36-41.

Davy.
1836—De la garantir le fer-blanc de la corrosion produite par l'eau de mer. Soc de l'Encouragement Bul v 35, p 72.

Deterioration of structures exposed to
1923 sea action. Engineer v 136, p 91.

Diegel.
1902-3—Corrosion of metals in seawater. Inst Civil Eng Pro v 153, p 406-7.

Duncklee, John B.
1892—Iron wharf at Fort Monroe, Va. Am Soc Civil Eng Trans v 27, p 115-24; discussion p 129-72.

Effects of sea water on iron.
1837—J Frank Inst v 23, p 483.

Ellis, S. H.
1914-5—Corrosion of steel wharf at Kowloon. Inst Civil Eng Pro v 199, p 133-40.

Flinn, A. D.
1924—Examples of graphitic corrosion. Chem & Met Eng v 30, p 48.

Grover, J. W.
1868-9—Corrosion of wrought iron in sea water. Inst Civil Eng Pro v 28, p 288-9.
1870-1—Description of wrought iron pier at Clevedon, Somerset. Inst Civil Eng Pro v 32, p 130-6.

Hadfield, R. A.
1921-2—Corrosion of ferrous metals. Inst Civil Eng Pro v 214, p 83-140, plates p 141-71; discussion p 173-83, correspondence p 183-95.
1923—Corrosion of ferrous materials with special reference to their resistance to the action of sea-water. XIIIth International Congress of Navigation, London, 1923.

McKaig, E. J.
1914-5—Subaqueous corrosion of steel. Inst Civil Eng Pro v 199, p 201-5.

Mallet, R.
1840—On the corrosion of cast and wrought iron in water. Inst Civil Eng Pro v 1, p 70.
1841—Corrosion of cast and wrought iron in water. J Frank Inst v 31, p 126-8, 210-12.

Matthews, Wm.
1914-5—Pitting of wrought iron piles. Inst Civil Eng Pro v 199, p 155-9.

Meik, C. S.
1914-5—Corrosion of iron and steel piles. Inst Civil Eng Pro v 199, p 147-9.

Merrick, J. V.
1856—History and construction of iron lighthouses. J Frank Inst ser 3, v 31, p 145-50.

Metallic piers and piles.
1864—J Frank Inst v 78, p 300-1, from the London Artizan, Sept., 1864.

Mitchell, James.
1923—Cutting steel piling below low water level. Engineering, v 116, p 103-4.

Mushet, D.
1840—Analysis of a piece of iron heel post converted by the action of seawater into a substance resembling plumbago. Inst Civil Eng Pro v 1, p 3.

Parker, G. H.
1923—Chemicals protect metals from marine animals. Port & Terminal v 3, no 4, p 8.

Percy.
1850—Action of seawater on copper. J Frank Inst ser 3, v 19, p 137-8.

Procédés de préservation du fer contre
1923 la rouille par les sels de chrome. Génie Civil v 83, p 284.

Redman, J. B.
1845—Gravesend Terrace pier. Inst Civil Eng Pro v 4, p 222-50.

Robinson, J.
1889-90—Barry docks works. Inst Civil Eng Pro v 101, p 129-51; discussion p 152-72; correspondence p 173-85.

Screw pile pier in Africa.
1892—Eng News v 28, p 320.

Screw piling for a pier at Blankenberg,
1895—Belgium. Eng News v 33, p 360.

Shelford, Frederick.
1914-5—Durability of steel piles in West Africa. Inst Civil Eng Pro v 199, p 166-7, part of discussion.

Skinner, Frank W
1915—Life of iron and steel structures. Inter Eng Cong San Francisco, 1915, Materials of eng vol p 390-464.

Tests on sea water corrosion of struc-
1922 tural materials. Eng & Contr v 57, p 530; from London Times Eng Sup.

Toch, M.
1903—Permanent protection of iron and steel. Am Chem Soc J v 25, p 761.

Vogel.
1839—Action of alkaline solutions on some metals. J Frank Inst ser 2, v 23, p 343-4.

Walmisley, A. T.
1914-5—Corrosion of Prince of Wales pier, Dover. Inst Civil Eng Pro v 199, p 220.
1915—Notes on corrosion in iron and steel structures. Inter Eng Cong San Francisco, 1915, Materials of eng vol p 648-656.

Webb, E. B.
1862—Durability of cast iron in sea-water. J Frank Inst v 74, p 327-30.

Wilkinson, H.
1840—Action of sea water upon iron. J Frank Inst v 30, p 66-8.

MISCELLANEOUS

Ahern, George P.
1904—Tests of Philippine woods. Table showing effect of preservative treatment with creosote upon the strength of the four Philippine woods, apitong, ipil, betis, and lauan.
1912—Manuscript report. Philippine Islands, Bur Forestry bul 11.

Aristophanes.
424 B. C.—The Knights. Line 1308. Everyman's Library, edition. London, Dent.

Armstrong, A. K.
1916—Greenheart used in Panama Canal is a timber with exceptional qualities. Eng Rec v 73, p 149-50, 180-1.

Atwood, William G.
1923—Problems and plans of the committee on marine piling investigations, National Research Council. Am Wood Preservers Assoc Pro v 19, p 457-65.

Barron, J.
1881-2—Buckie Harbour, (Moray Firth) Inst Civil Eng Pro v 70, p 350-60.

Carbutt, Edward.
1895-6—Ravages of the teredo in San Francisco harbour. Inst Civil Eng Pro v 125, p 265.

Charleston, South Carolina. Statistical 1923 digest of the port. South Atlantic Ports v 4, p 151-6.

Deterioration of structures of timber, 1920 metal and concrete exposed to the action of sea water. First report of the committee of the Inst Civil Eng.

Deterioration of structures of timber, 1922—metal and concrete exposed to the action of sea water. Second (Interim) report of the committee of the Inst Civil Eng.

Deterioration of structures of timber, 1923 metal and concrete exposed to the action of sea water. Third (Interim) report of the committee of the Inst Civil Eng.

Dumonteil.
1852—Bois de la Guyane. Soc de l'Encouragement Bul v 51, p 399-403.

Ferrel, W.
1885—Harmonic analysis of tides at Governor's Island, N. Y harbor. U S Coast and Geodetic report p 489-93.

Jacksonville, Florida. Statistical digest 1923 of the port. South Atlantic Ports v 4, p 84-90.

James, J. W.
1890-1—Timber in the tropics; the teredo navalis and white ant. Inst Civil Eng Pro v 103, p 337-41.

Jones, W. A.
1910—Protection of submarine structures. Eng Mag v 38, p 876-82.

McCandless, B.
1916—The harbor of St. Thomas. U S Naval Inst v 42, p 1619-22.

Maiden, J. H.
1894—Turpentine tree. N S W Agr Gaz v 5, pt 7, p 463-7.

Marine borers and their work shown in 1922 exhibit. Eng News-Rec v 88, p 419.

Marine borers subject of engineering 1923 discussion. Eng News-Rec v 88, p 543.

Matthews, Wm.
1903-4—Resistance to the teredo of Karri and Jarrah timber. Inst Civil Eng Pro v 158, p 137-9.
1905—Harbors of Great Britain. Am Soc Civil Eng Trans v 54, pt A, p 159-80.

Mell, C. D., and **Brush**, W. D.
1913—Greenheart. U S Dept Agr Forest Service Cir 211.

Methven, C. W.
1912-3—Durban Harbour, South Africa. Inst Civil Eng Pro v 193, p 1-31.

Mitchell, Henry.
1886—Circulation of sea through New York harbor. U S Coast and Geodetic report p 409-32.
1887—Report on results of physical surveys of New York harbor. U S Coast and Geodetic report p 301-11.

Molesworth, Guilford.
1895-6—Action of the teredo on Jarrah at Colombo. Inst Civil Eng Pro v 125, p 272.

Moore, Paul.
1923—That worm is still boring. South Atlantic Ports v 4, p 180-1.

National Research Council opens fight 1922 on marine borers. Eng News-Rec v 88, p 335.

Ocean out-fall sewer syphon under the 1923 Middle Harbor, Sydney, N. S. W. Engineering v 115, p 547-50.

Old Testament.
Vulgate: 2 Kings, 23:8; Sept: Proverbs, 12:4; Sept: Proverbs, 25:20.

Pickwell, R.
1892-3—Construction of concrete graving dock at Newport, Mon. Inst Civil Eng Pro v 111, p 75-85, discussion p 86-128.

Protecting piles from teredo.
1918—Sci Am v 119, p 128.

Ramsbotham, Joshua F.
1913—Freemantle graving dock: steel dam construction for north wall. Am Soc Civil Eng Trans v 76, p 1942.

Report on San Francisco Bay marine 1921 piling survey. Committee publication, San Francisco 104 p.

Report on San Francisco Bay marine 1922 piling survey. Committee publication, San Francisco 82 p.

Report on San Francisco Bay marine 1923 piling survey. Committee publication, San Francisco 48 p.

Resistance of greenheart to marine 1920 borers. Eng News-Rec v 84, p 704.

Resistance of greenheart to various ma-1920 rine borers. U S Dept Agr Forest Products Lab Tech notes no 96.

Resistance of piles to attacks of te-1905 does. Eng News v 53, p 451.

Savannah, Ga. Statistical digest of the 1923 port. South Atlantic Ports v 4, p 118-9, 122-6.

Shenton, H. C. H.
1922—Pile foundation and clay. Canadian Eng v 43, p 442-3.

Smith, Alexander R.
1920—Port of New York annual. Smith's Port Publishing Co.

Staniford, Chas. W.
1917—Unusual coffer-dam for 1000-foot pier, New York City. Am Soc Civil Eng Trans v 81, p 498-542, discussion p 543-81.

Starling, William.
1892—Some notes on the Holland dikes. Am Soc Civil Eng Trans v 26, p 559-656, discussion p 656-700.

Stevenson, Robert.
1824—Account of the Bell-Rock lighthouse. Edinburgh, 533 p.

Stevenson, Thomas.
1856—Harbours. Encyclopaedia Britannica ed 8, p 216-25.

Strassenbrückenbäuten in Altserbien 1922 und Mazedonien. Oest Ing Arch Ver v 74, p 135-6.

Tampa, Florida. Statistical digest of 1923 the port. South Atlantic Ports v 4, p 248-52.

$2,500,000 asked to fight teredo.
1922—Eng News-Rec v 88, p 461.

Van Iterson, G., and **Söhngen,** N. L.
1911—Over onderzoekingen verricht omtrent geconstateerde aantasting van het zoogenaamd manbarklac. De Ingenieur v 21, p 321-2.

Von Schrenk.
1922—Marine borer problems in the vicinity of New York. Munic Eng J City of N Y v 8, p 57-80.

Wagoner, Luther.
1909—Notes upon docks and harbors. Am Soc Civil Eng Trans v 62, p 135-58, discussion p 149-56.

Wood borer takes the count; protecting 1921 piling by cement gun. Sci Am v 124, p 111.

Young, E. W.
1892-3—Biloela graving dock Cockatoo Island, Sydney Harbour, N. S. W. Inst Civil Eng Proc v 111, p 48-58.

ADDENDA
TO
NEW YORK HARBOR REPORT

Since the preparation of this report Mr. R. T. Betts, chairman of the committee, received from Mr. Allen Spooner of Allen N. Spooner & Co., Inc., a section of the pine timber cover plates from the outlet nozzles of the Passaic Valley sewer, which terminates in the channel near Robbins Reef Light in a depth of 40 feet below mean low water.

Mr. Van Duyne, Chief Engineer of the Passaic Valley Sewerage Commissioners, states that this timber was new when installed and that it has been in place not more than four years. The cover plates were temporary, screw bolted to a cast iron nozzle and placed in such a manner that broken stone filling could be put around the nozzles for support. They lay in a horizontal plane, the nozzles pointing upward.

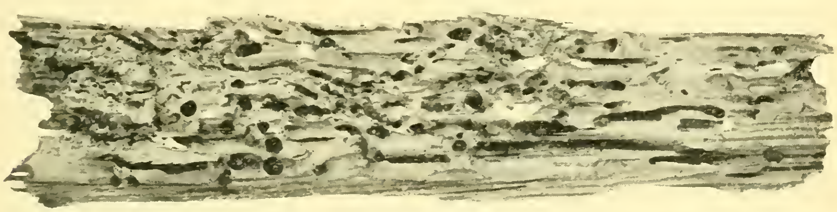


FIG. 169—SECTION FROM COVER PLATES OF PASSAIC OUTLET SEWER NEAR ROBBINS REEF LIGHT, NEW YORK HARBOR

The section shown in the illustration (Fig. 169) is from the plank joining the cover plates and was removed May 31, 1924.

As may be seen from the illustration, the damage by shipworms was quite heavy and as it occurred in what by some has been considered territory free from serious attacks by marine borers, the information is thought to be of sufficient importance to justify its being appended to this report.

Living organisms were taken from the timber at the time this specimen was obtained.

INDEX

U

National research council. Division of engineering and industrial research.

Marine structures, their deterioration and preservation. National research council, 1924.